Achieving Curriculum Change in Engineering Education

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Engineering Education:
Transformation and Innovation

UNESCO Report

UNESCO Report

Engineering Education:

Transformation and Innovation

A Monograph commissioned by UNESCO.

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United Nations Educational, Scientific and Cultural Organization

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Authors

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Retired Vice-Chancellor & President of RMIT University

David Beanland is an electronic engineer who specialised in semiconductor and integrated circuit technology. His career was always committed to education. It included 4 years in industry and research laboratories and 21 years in engineering education followed by 17 years in university management. He graduated with BEng (Hons) from University of Melbourne and MSc and PhD from the University of Salford. His first teaching position was in Electrical Engineering at Caulfield Technical College where he was given responsibility for the design and development of the professional diploma courses in Electrical Engineering and Electronic Engineering conducted by the Victorian Education Department's Colleges. In 1968 he was appointed Head of the Department of Communication and Electronic Engineering at RMIT. This role included responsibility for the design, approval and delivery of new 4 year degree courses leading to Bachelor of Engineering in Communication or Electronic Engineering. These courses had strong design and systems components. The Department also introduced Graduate Diploma, Masters and PhD programs. In 1979 he was appointed Dean of the Faculty of Engineering with responsibility for the operation and development of the then 7 Engineering Departments at RMIT. During this period he was responsible for Chairing the Engineers Australia Accreditation Panel for Electrical, Electronic and IT degree courses and a member of many organisations relating to engineering education and research. In 1984 he was appointed Associate Director (Academic) at RMIT with responsibility for the then 6 Faculties and in 1989 as Director and then Vice-Chancellor and President responsible for RMIT University until retiring in 2000. His career has involved participation in every issue involving universities. Particularly important have been the development of international education, the commencement of RMIT International University Vietnam, the use of IT and computers to assist in the educational process, the cooperation with industry in applied research projects, multi-level education, university accountability through the introduction of quality processes in universities, open learning and community partnerships. Some of these interests have extended into retirement!

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Roger Hadgraft is an ALTC Discipline Scholar in Engineering and ICT. He has led curriculum change in several engineering disciplines, with a focus on problem/project-based learning (PBL) at RMIT, Monash and Melbourne Universities. At RMIT, he also co-established the multidisciplinary Master of Sustainable Practice. In 2012, Roger returned to RMIT to lead a new, cross-disciplinary program in Sustainable Systems Engineering. He is a Governing Board member of the International Research in Engineering Education Network.

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Foreword

This publication began in 2010 with a response from David Beanland to an article in *Engineers Australia* Magazine entitled "Engineering for Development", discussing the importance of engineering in development, with reference to the UNESCO Report "Engineering: Issues, Challenges and Opportunities for Development", published in October 2010. The role of engineering as the major driver of social and economic development and change since and before the Stone Age was emphasised, noting that the Stone Age did not end because of a shortage of stones, or the Bronze and Iron Ages end because of a shortage of copper, tin and iron, but because of engineering and technological innovation.

The Report also reflected increasing concern regarding the decline of interest and enrolment in engineering by young people, due largely to perceptions of engineering education as boring and hard work. The consequent decline of engineering capacity around the world is already having a serious impact on development, exacerbated by brain drain in lower income countries. This is at a time of increasing need for engineering and technology to address major global issues, including the reduction of poverty, promotion of sustainability, climate change mitigation and adaptation and recovery from the global financial crisis. There is a particular need to promote awareness and understanding of engineering to the public policy makers and planners.

While the world is not yet running out of engineers, there is a need for problem-solving and innovation in engineering, especially in engineering education. Fortunately, the above issues are linked – when young people see that engineering is a key and major part of the solution to the global issues we face, they are attracted to it. This attraction needs to be reinforced by making engineering education more interesting – to be responsive to such challenges engineering, as a problem-solving profession, needs to make more use of problem- and project-based learning and student-centred approaches. As David Beanland and Roger Hadgraft observe, the five major waves of technological innovation over the last 200 years have all been reflected in subsequent innovations and transformations in engineering education, albeit with a time lag, most recently of between 10 and 20 years. The major challenge for engineering in the post IT/biotech wave is to transform engineering education with problem and project based learning approaches, using network and web-based resources, to reflect changing paradigms and modes of knowledge production as we move into the sixth wave of sustainability, whole system design and green technology.

UNESCO commissioned this publication to have a focus on the need to make engineering education more interesting and relevant at a time of changing global needs, issues and contexts, making use of the opportunities provided by ICTs and the internet. There is a particular need to review university and related courses in terms of new learning and teaching approaches, curricula and materials, with just-in-time, hands-on approaches that emphase engineering as a problem-solving profession with applications to address global issues. This publication examines the global situation and condition of engineering and engineering education, engineering capacity and capacity needs. The overall goal is to explore these issues and challenges, and opportunities for change, and to share information, experience, practical ideas, advocacy and examples of educational opportunities. The target audience consists of engineering educators, planners, policy makers and the wider public around the world, with particular reference to developing countries, to promote the development of engineering.

Tony Marjoram, PhD, CPEng, FIEAust
Head of Engineering, Division of Basic and Engineering Sciences, UNESCO, 2001-2011
Founding Editor and Coordinator, UNESCO Engineering Report

Executive Summary

This report was commissioned by UNESCO to address why there is a need for transformation of the education of engineers, what it would entail and to consider how it could be achieved. There have been many calls for transformation as a consequence of the widespread undersupply of new entrants to the profession and concern about inadequacies in their preparation. The authors explore the educational approaches that can be used to address this important problem. Transformation of engineering education requires an understanding of the issues and a commitment to implement change by the key stakeholders. We have endeavoured to define the pathway that needs to be travelled.

The Role of Engineering in Society

Engineering is one of our major professions. As implementers of the technological solutions upon which our communities depend, engineers fulfil an essential role. Engineers have the ability to solve the issues relating to the development of our communities in efficient, effective and sustainable ways using appropriate technology. They provide the leadership in the technology related issues that have an impact on our societies. They have a key role in delivering the innovations upon which the progress of our societies depends. As our dependence on technology is increasing rapidly and advances in technology are proceeding at an ever increasing pace, it is apparent that our dependence upon engineers will be even greater in the future.

Review of International Reports

Engineering Education has been the subject of many reviews and reports over the last decade. Reports have emphasised the need for transformation, the strategies which are available to drive change and the importance of action in a rapidly changing technological environment. The key international issues and contributions are discussed and interpreted to establish a foundation for the consideration of this subject and the development of recommendations that could lead to the transformation of engineering education.

Attraction of Students into Engineering and Meeting their Needs

There are many reasons why students are not attracted to the study of engineering. The role of engineers is not well understood in our societies. It is considered to be less rewarding than some other professions. Also engineering courses are viewed as being uninteresting or too difficult and so fewer students than our societies require are motivated to undertake them. The important contribution that engineers make to society is not sufficiently emphasised for, or promoted effectively to, potential students. In almost every country, problems exist because insufficient engineers to meet the employer's requirements are graduating from our universities as a consequence of the poor attraction power of engineering education programs and high failure/dropout rates.

Some of the larger developing countries have strongly encouraged the growth of engineering education enrolments to meet the significant number of employment opportunities. However, the variation in standards achieved by engineering graduates is also a significant problem for a profession which operates internationally. The continuing rapid rate of expansion of technology with the evolution of numerous fields of specialisation, and the importance of the development of the appropriate personal attributes, capabilities and characteristics for successful engineering practice, are issues that require attention in engineering education everywhere.

Achieving Community Relevant Engineering Education

In many countries there are problems with the quality of the graduates. There is also an under representation of females in the cohort of graduate engineers. A key issue has been the tendency for engineering education to become engineering science education through an overemphasis on the technology content with a consequent neglect of the personal capabilities and attributes that successful engineers require to develop and implement responsibly appropriate technological solutions. This has led to numerous calls for transformation in engineering education by individuals and organisations. However they have not resulted in the necessary changes by the universities. This publication seeks to address all of the many aspects associated with this complex issue. Key questions include: Why is there a shortage of engineers? How can it be addressed? Why does engineering education need to change? What are the principles that should guide change? What methods can be utilised? How should courses be constructed? Why have universities been reluctant to change? How can the conditions to achieve the necessary changes be established?

Much of this publication addresses the requirements for a quality engineering education and how it can be best delivered within an academic institution. It considers the issues faced by engineering education, why it needs a transformation, what should be its objectives and how they could be realised. The role and relationship with the professional bodies and the engineering employers is also considered. The international accords which have specified the behaviours that are required to be demonstrated by engineering graduates are considered, as they provide the foundation for a more effective pathway to the education of engineers. These accords must have a direct relationship to the objectives of engineering education programs at all levels and the curriculum that should be designed and presented by the educational institutions to achieve their realisation.

Curriculum Design

The primary focus of this publication is the development of best-practice engineering education to ensure the required outcomes. Consequently it places particular emphasis on the detail of curriculum design for transformation and proposes possible implementation strategies. The approach proposed for transformation is innovative, while being practical, as it is based on the experience of various institutions which have introduced some elements of the changes recommended. It is applicable to both existing and planned engineering academic programs and while it can also be cost and performance effective for the former, it may be easier for the latter. This publication has relevance for engineering education programs in all specialisations. Engineering education must become relevant to the needs of the profession in a rapidly changing world and move from its current focus on engineering science to providing graduates with the expertise to responsibly apply technology to the benefit of their communities.

Exemplars

It is encouraging to note that the approaches to engineering education which are recommended in this publication are being practised in the Franklin W Olin College in USA and have been chosen by the new Singapore University of Technology and Design, to form the basis of its engineering education program commencing in 2012.

Project Based Learning

A new curriculum is proposed with sufficient detail to facilitate the implementation of the proposed approach. It utilises the concepts of project based learning and the formation of learning communities. The curriculum is broadly based and does not require the choice of a particular engineering specialisation in the first two years. Projects are used as a vehicle to provide interest, context and motivation while developing the desired engineering attributes such as creative problem solving and innovation, capability to analyse the issues involved in a system problem, ability to find, understand and utilise information, teamwork, leadership and communication skills, ethical and environmental responsibility, and awareness of business issues. Projects would be used throughout the program with increasing complexity.

Student-centred Learning, Collaborative Learning and e-Portfolios

The essential theoretical topics in the curriculum would be designed to assist with the projects that the students are undertaking. They would utilise student centred learning using learning communities with facilitation by academic staff, senior students, experienced engineers from industry and/or retired engineers. Each student would create their own e-portfolio around their own career plan. The portfolio is their collection of evidence of their attainment of the required graduate capabilities required for their intended engineering practice. The objective is to encourage a move away from the ineffective staff dominated, lecture based, taught mode, by implementing a sustainable and more effective student-centred learning format that can be built around student inquiry and utilise the extensive web-based engineering education resources which are now available. Information technology based resources would also be used for communication between students and staff, topic presentations, assessment, student portfolios, simulation, computation and design. This publication explores the issues associated with the implementation of these innovations.

Multidisciplinary Fundamentals

Projects create the incentive to explore the mathematical, scientific and engineering principles whose understanding is essential for their exploration. They also provide students with the opportunity to act as trainee engineers from the beginning of their course. Their involvement with issues across the spectrum of engineering activity reflects the multidisciplinary nature of most realistic engineering projects. They also assist the student to select a field of specialisation for the later years of their program, based upon the interests that they have acquired.

Learning Technologies

The many issues associated with implementation of a realistic approach to effective and efficient engineering education using information and communication technologies as an effective learning medium are explored. These technologies utilise the skills that many students now possess, while being consistent with the methods utilised in engineering organisations. However, it will be a major change experience for most university education systems, and guidance in how to realise this objective is given. It is also important for the development of the graduates to be effective life-long learners.

Suggested Program Implementation

The achievement of change is dependent upon the acceptance that program transformation should and can be implemented by the key stakeholders. There is consideration of, and detailed suggestions relating to, program implementation so that clear guidance can be available to those universities, departments and staff that are committed to pursuing transformation.

Change within Universities

Universities are respected and responsible institutions that fulfil a number of essential roles in our communities. Their mission embraces teaching, research and community outreach across many disciplines. They aspire to leadership and status which is usually accorded through research performance. This, unfortunately, places the educational role, which is usually their major business, in a secondary position. As institutions they have been resistant to change, especially in education where the dominant paradigm remains staff-centred teaching, in contrast to student-centred learning which should be the objective.

Universities must take responsibility for the problems created by the current deficiencies in engineering education. No other organisations can solve the problems which exist. No other organisations are responsible for the curriculum details, the learning processes utilised, the student's formation and their assessment. They are ultimately responsible for defining the role that they require the academic staff to undertake and the outcomes that they are expected to achieve.

The professional engineering organisations, which have set clear attributes that should be achieved by engineering graduates, are responsible for the accreditation processes that have been proven inadequate to achieve the transformation required. They must play a more effective role by ensuring that the specified essential graduate attributes are possessed by all graduates. While they are unable to control the internal processes of the universities, they do control the educational standards required and must be encouraged to play a leading role in achieving the desired transformation.

The challenge which this publication delivers is for universities to examine how the internal barriers to transformational change in relation to engineering education can be removed, and incentives provided to implement the new approach which is outlined. The employers, professional engineering organisations and governments as key stakeholders also have a role to play in achieving the necessary changes. The content of the publication is applicable to all countries, independent of their stage of development.

An Action Plan

The need to transform engineering education is relevant to every country. It has escaped attention for too long. As engineering is a major profession, it is essential in the public's interest. Its implementation requires the participation and commitment of all major stakeholders. Cooperation and collaboration is essential. It is recommended that an appropriate Action Plan is developed by the stakeholders in each country to achieve the required transformation of their engineering education provision.

Acknowledgements

The Authors wish to firstly acknowledge the support and advice received from Dr Tony Marjoram throughout all phases of this project. His advice has been invaluable, his experience and insight most pertinent, and his contributions to the final report are significant. He has directly contributed by providing the Foreword and Contributed Panel No. 4.

We were of the opinion that this report would be enhanced if we invited relevant contributions from engineers who were expert in some of the aspects most pertinent to the Report. These contributions are separately identified in panels inserted throughout the main text and are standalone considerations of their particular subject. The authors acknowledge these valuable insights provided by the Contributing Authors who responded generously within the tight time constraints of this project, sharing their experience in the Panels included throughout this monograph. We thank them sincerely for their valuable contributions.

Contributed Panels

Note that **references** within the Contributed Panels are listed at the end of each Contributed Panel. References for the main report are listed numerically at the end of the report.

Contents

1. Introduction to the Report

The recent UNESCO Report on Engineering: Issues, Challenges and Opportunities for Development [1] highlighted the importance of engineering and consequently engineers, for the implementation of sustainable global development. It is widely understood that engineers are essential to conceive and implement the technological developments upon which our societies increasingly depend for their existence and progress. Engineers have been, and will continue to be, essential for the development of our various societies. The Report on Engineering gives detailed information and commentary on its nature, scope, impact, development, diversity, importance and evolution from various perspectives and should be referred to when general information on engineering is required. It also noted in many sections that transformation of engineering education is essential if the engineering profession is going to continue to fulfil its obligations to its communities.

The Report on Engineering indicated that most countries have a significant deficiency in the supply of engineers that are essential to meet their national requirements. There was also a clear message that it is necessary to examine in detail the provision of engineering education and address systemic deficiencies if this situation is to be adequately rectified. The failure of our education systems to deliver appropriate numbers of proficient engineering practitioners is a highly significant global problem as engineers perform a critical role in the provision of vital systems and services including: energy, water, infrastructure, manufacturing, development, transport, mining, construction, defence, communication and health. The shortfall in engineering expertise comes at a time of rapid changes in technology and a growing demand for its application to most areas of global development. The education of engineers must also ensure that they can accept responsibility for the future sustainability of these systems.

The UNESCO Engineering Report [1] also noted that:

"One of the greatest challenges for engineering is the need to make engineering education more interesting and relevant at a time of change in global needs, issues and contexts, such as the rising concern regarding climate change, and the opportunities provided by information and communication technologies in engineering and engineering education. There is a particular need for university and other courses to be reviewed in terms of the appropriateness of the desired outcomes, the effectiveness of the learning and teaching approaches, and the appropriateness of the curricula. It will be suggested that it is possible to emphasize the development of engineering skills and expertise through a problem-solving approach with applications to address both local and global issues such as poverty reduction, sustainable development and climate change mitigation and adaptation."

This publication aims to examine all the issues associated with the education of professional engineers. It considers the approaches that have been used, the deficiencies that have been identified and the successes that have been reported. The objective is to analyse the current situation, to establish clearly the desired outcomes, and to consider, propose and describe, methodologies that can contribute to significant improvements in the effectiveness of professional engineering education in all counties and all universities. The extent and magnitude of the deficiencies in our current systems of engineering education have been widely reported and they will be carefully analysed. These issues have produced many references in the literature to the need for transformation. However the complexities of the issues have shown that the realisation of the necessary transformation is very difficult.

This report will endeavour to examine engineering education as a vehicle whose objective is to achieve the effective formation of professional engineers. It will examine all that this entails and explore the means by which this goal may be effectively realised. The primary objective of this report is to facilitate the changes necessary to achieve a major transformation of engineering education, rather than the continuation of the current pathway of minor improvements. The challenge is to bring innovation to the process of the transformation of engineering education in the interest of the communities that engineers serve.

Transformation of engineering education is a complex issue because engineering education is more than a just program of learning; it is a complex and diverse system with a very large number of variables of which the program of learning is just one factor. To achieve the major change which is considered necessary, it is essential to consider all the factors which influence this system. Trying to achieve enhancements without considering the total system will inevitably lead to sub-optimal outcomes. The goals of engineering education are generally agreed, but the nature of the changes that need to be implemented to enable their achievement, has proved to be the stumbling block in the past. Even more difficult is the identification of the factors that prevent change and proposing appropriate ways of overcoming them.

Universities (this word is used throughout this publication as the collective descriptor for institutions that educate professional engineers) are not institutions that embrace change easily. However the world which universities exist to serve has changed extensively, largely as a result of technological development, over the last century and it will continue to change. Universities will not be able to stand aside from these changes. Interestingly they have adapted to change in their research activities to enable their impact and importance to be retained, but they resist adaptation to change in their education activities. Can universities use the opportunities that changes can bring to improve engineering education? Can university leaders and engineering academics deliver the transformational changes and innovation in engineering education that their countries require? If this publication can assist that process it will have achieved its objective. Its aim is to stimulate the transformational change that is required in established engineering education programs and to guide those seeking to establish new programs.

1.1 The Number of Engineering Graduates

The most visible and highly significant issue facing the profession of engineering is the widespread undersupply of engineering graduates. While the statistics are incomplete and inadequate for direct comparison, most countries report [1] that the number of graduates from their professional engineering (degree) programs is inadequate. China, India and the USA have moved to establish national engineering education programs that produce a sufficient quantity of graduates to meet their needs for technological development on a sustainable basis. For China it is difficult to obtain accurate figures, although they have been estimated to graduate 517,000 in 2007. A more recent estimate was 650,000, but these figures are likely to include sub 4 year graduates. The most reliable data is from 2004 [2] which estimated that the number of 4 year degree graduates from all engineering and IT disciplines were: China 349,000, India 112,000 and USA 137,000.

It should be noted that the statistical analysis of the numbers of engineering graduates is complicated by the mobility of engineers between countries, data deficiencies, differing levels of qualifications and the number of specialisations that may be included in the data. Further complications arise because not all engineering graduates seek employment as engineers. National reports do, however, convey a consistent picture of a major shortfall in the number of engineers being produced annually with the possible exception of China and South Korea. It is also clear that the number of engineers in USA and India is still below projected national requirements.

This shortage is occurring when the scope of engineering work is growing as a result of technological advances and the need for engineering skills is increasing as the requirement for development places demands on resources and infrastructure. The concern for the global environment requires a commitment to new technologies to achieve the sustainability which is now an essential element of all development projects. Additionally some countries have an ageing engineering workforce that needs to be replaced.

The available statistics indicate that there has been an increase in absolute enrolments in engineering degree programs over the last decade, but a decline in the relative percentage of engineering enrolments as a proportion of total university enrolments in most countries over the

Table 1: Growth of Engineering Institutions in India.

Year	Number of approved Institutions	Number of U/g Students (all years)
1997-8	562	134,894
2002-3	1195	359,721
2005-6	1476	517,018
2008-9	2388	820,000

same period. The number of female engineering graduates has been increasing slowly from a very low base in most countries, while in some others the numbers are stagnant.

A significant issue is the capacity of developed countries to solve their professional engineering staff shortage by attracting well educated engineers from developing countries by offering interesting employment with attractive salaries. These graduates have often have been educated in that developed country and are especially attractive employees sought by international companies. However, their benefit occurs at the expense of the developing countries that urgently need to enhance their engineering capabilities. This raises difficult ethical issues that are usually ignored. Australia is an example of a country where this occurs. A recent report [3] concludes that the current annual number of engineering graduates from its universities meets approximately half of that country's employment requirement. The balance of the annual recruitment is met from the employment of international students who have studied in the country and by the employment of engineers who are attracted from other countries.

In most countries the limited and inadequate supply of engineering graduates and the very low percentage of female graduates are both serious problems. Fundamentally these problems occur because engineering and engineering education are not attractive to potential students. This has serious consequences for economic growth, for national development, for essential infrastructure, for sustainability and for technological innovation. While the failure to attract potential students may result from their lack of knowledge about, or understanding of, engineering, it is essential that this issue be addressed as a major dimension of any realistic transformation of engineering education. The responsibility for action should be the shared responsibility of the professional bodies, the employers and the universities (and possibly the government). This may be the reason why it has not been adequately addressed.

There has been declining interest in science, technology and engineering by young people in Japan and USA, and a serious shortage of engineers in countries which include Germany, Australia, Africa, Brazil, Argentina, is evident [1].

The situation in India is most interesting and has been reported in detail [4]. There has been a rapid expansion of engineering institutions and engineering (including IT) students as shown in Table 1.

There is still a massive unmet demand for engineering graduates in India and an additional 880 new institutions were to be added for 2009-2010. The IT industry is growing at 14% per annum and serves to attract students to engineering and IT degree programs. Such high growth rates make adequate staffing a key and difficult issue. Even in 2008-9 engineering students were only 6% of total university undergraduates. The ratios of scientist/engineers per 1000 of the population are quoted as: India 3.5, China 8.1, South Korea 45.9, USA 55, Germany 76, Israel 76 and Japan 110.

1.2 The Quality of Engineering Graduates

While the shortfall of engineering graduates is a problem for most countries, a related issue of similar magnitude is the widespread reference in national reports to the inadequate quality of many engineering graduates. When used in this context quality means suitability for purpose of engineering graduates, or more specifically, the capability of engineering graduates. There are widely held views that many contemporary engineering graduates are deficient in the capabilities that are required of engineers. While it is to be expected that the graduates from any engineering program will have differing capabilities and attributes, these references indicate that many graduates are unable to undertake engineering activities that should be reasonably expected of a graduate engineer. This issue will be addressed in greater detail subsequently, but it is important to flag it now as another headline concern about engineering education.

There are many reasons for this perceived inadequate quality. They include some or all of:

- Deficient curriculum
- Inadequate development of the personal capabilities of graduates
- Academic staff with insufficient engineering experience
- Overloaded staff &/or insufficient guidance available for students
- Inadequate facilities
- Insufficient financial resources
- Inappropriate educational pedagogy
- Unrealistic standards
- Ineffective performance evaluation and quality management

The management of the quality of university programs and graduates is a very important concept that is not well understood and is consequently only occasionally an integral component of university operations. It is seldom a concept that it used with useful consistency and insight. The issues relating to the definition of, and realisation of, quality outcomes in engineering education programs will be discussed in Section 6.7

In some countries the issue of the numbers of engineering graduates and their quality is further clouded by use of the title "engineer" by students who have not completed a program that provides the professional formation specified for an engineer as defined in Section 3. These programs, while preparing people who will be part of the total engineering workforce, may be more accurately described as leading to an engineering associate or an engineering technician. Such programs are important in every country as employees with these different skills and knowledge are an essential component of the technical workforce. While engineering technologists (or associates) and engineering technicians make an important contribution to engineering activities and projects, the graduates of such programs cannot be expected to fulfil the role of professional engineers without further development. This report is focussed upon the education of professional engineers however the educational relationship with engineering technologists and engineering technicians is addressed in Section 6.9.

Engineering roles are evolving rapidly with developments in technology continually increasing in complexity and expanding the fields of application. These changes will continue to place demands on the requirements of engineering education programs. Engineering projects are becoming more multi-disciplinary requiring engineers with an extensive breadth of knowledge as well as expertise in relevant technical specialisations. Engineering education must be able to address this dichotomy.

1.3 Engineering and Engineers

To many people, engineering and the engineering profession is mysterious. The community realises that engineering has some relationship with technology and that its practitioners are broadly technically informed and competent with numerical and quantitative methods. It is also understood that engineers are commonly expert in some specialised aspect of technology. Engineers are understood to be practical people focussed on delivering outcomes or implementing projects while being good problem solvers. For these qualities they are well respected professionals, although engineering as a profession rates well behind the medical and legal professions with whom the public has a far more direct interaction. While engineers are clearly a group that are essential for society's smooth operation, there is a distance in the public's relationship with them that makes it less likely that they will encourage young people to consider a career as an engineer. There is also an obstacle facing the promotion of engineering as a career which arises from the commonly held belief that mathematics and engineering are difficult and that therefore it could be a risky option for anyone to pursue. This perspective is reinforced by the relatively high failure rates experienced by students in engineering courses in quite a few countries.

The situation is different in countries where technological skills bring a much higher probability of employment and reward. These circumstances exist in countries such as India and China and other developing countries, where there has been a highly visible growth of industry with strong national commitment to technological development.

The countries (mainly the developed economies) in which there is a declining percentage of university students studying engineering face a significant problem. While university student entrants are likely to grow steadily over the next one or two decades to approach approximately 40% of school leavers, many of the additional university entrants will not be outstanding performers in the fields of mathematics and science. Consequently growth in the university system is unlikely to result in an increase in engineering graduates. In many developed countries the percentage of university students studying engineering has dropped steadily to around 7% of the total undergraduate population.

A general understanding of engineering and a favourable view of the role of engineers by both the community and potential students is necessary if the number of engineering enrolments is to be increased to meet demand. Changing this perspective is a large and complex task that requires planning and investment. It will require a partnership between employers, universities and professional engineering organisations to develop this understanding through sustained marketing. It is a key issue when virtually all countries are affected by an undersupply of engineers. Which organisations are going to take the initiative to generate the sustained and wide-reaching action required to attract and to educate the number of engineers needed to adequately meet the future national and global requirements?

An interesting way to improve knowledge of what an engineer is, what they do and to interest potential students in engineering, is the use of the world wide web. Two such initiatives have recently been launched by Engineers Australia: Make it so [5] and EngQuest [6].

EngQuest is an interactive online program designed to help students achieve key learning outcomes in science, technology and mathematics. Primary and secondary students work in teams, at their own pace, applying their problem solving skills to a range of engineering projects. The projects include building catapults, model houses, bridges made from straws, giant newspaper domes, model dams and water wheels. Every project has specific outcomes for the students to achieve. Resources and background information are provided for teachers to help them deliver EngQuest in the classroom.

There is plenty of scope to use this medium effectively to enhance community understanding of engineering and to kindle the interest of students so that they may consider entering the profession. There have been several engineering programs recently from the UK and US – Richard Hammond's Engineering Connections [7], Big, Bigger, Biggest [8], Discovery Channel's Megabuilders etc [9] and Mythbusters [10] and Seven Wonders of the Industrial World [11]. Such resources are particularly important in those countries where the number of qualified science and mathematics teachers is inadequate.

The motivation of potential engineering students is also dependent upon improved understanding of the role that engineers play in, and their contribution to, their society. Motivation will be discussed in detail in Section 4.7. It will be shown that student motivation is one of the most critical factors determining their success in an engineering degree program. If they have chosen engineering with a workable knowledge of what an engineer does and why this is important for the development and operation of our societies, their likelihood of completing their studies successfully is greatly enhanced. Experience of, and success with, engineering type activities at school is also valuable, but unfortunately very few schools are able to provide such experiences.

Engineering employment has changed rapidly over the recent decades. It has moved from a largely government dominated employment sector to become a highly diversified sector with mostly private employers that vary in scale from small local companies to vast international organisations operating across a number of countries with multi-national workforces. They are often attractive employers and if there are insufficient engineers in their primary location they will seek engineering graduates from other countries. This recruitment can deplete the number of engineers that are available in developing countries. While the ethics of this outcome can be considered to be questionable, it does provide well remunerated experience to those engineers and may also provide the opportunity to gain valuable experience in international projects.

Communities are increasingly dependent upon technology, and consequently engineers, to deliver sustainably the solutions that they require for their development. These may include water, housing, electric power, roads, transport, information, communications, waste management, security, health, education, food, agriculture, mining, manufacturing and community infrastructure projects. Consequently we, and governments on behalf of their constituents, must all be concerned that there is currently a shortage of engineers, which is projected to continue, and an issue in relation to the quality of their education.

1.4 The Need for Transformation of Engineering Education

Engineering has been transformed by the explosion of knowledge in the last 50 years. It has provided new tools for the engineer and changed how they go about their responsibilities of providing the technological solutions that their communities require. The information technology revolution has been especially impacting as it has changed every aspect of how engineering is undertaken and changed equally significantly the tools available to implement engineering solutions. It has resulted in the complexity of solutions becoming greater as the problems that can be addressed effectively have been extended in scope and capability.

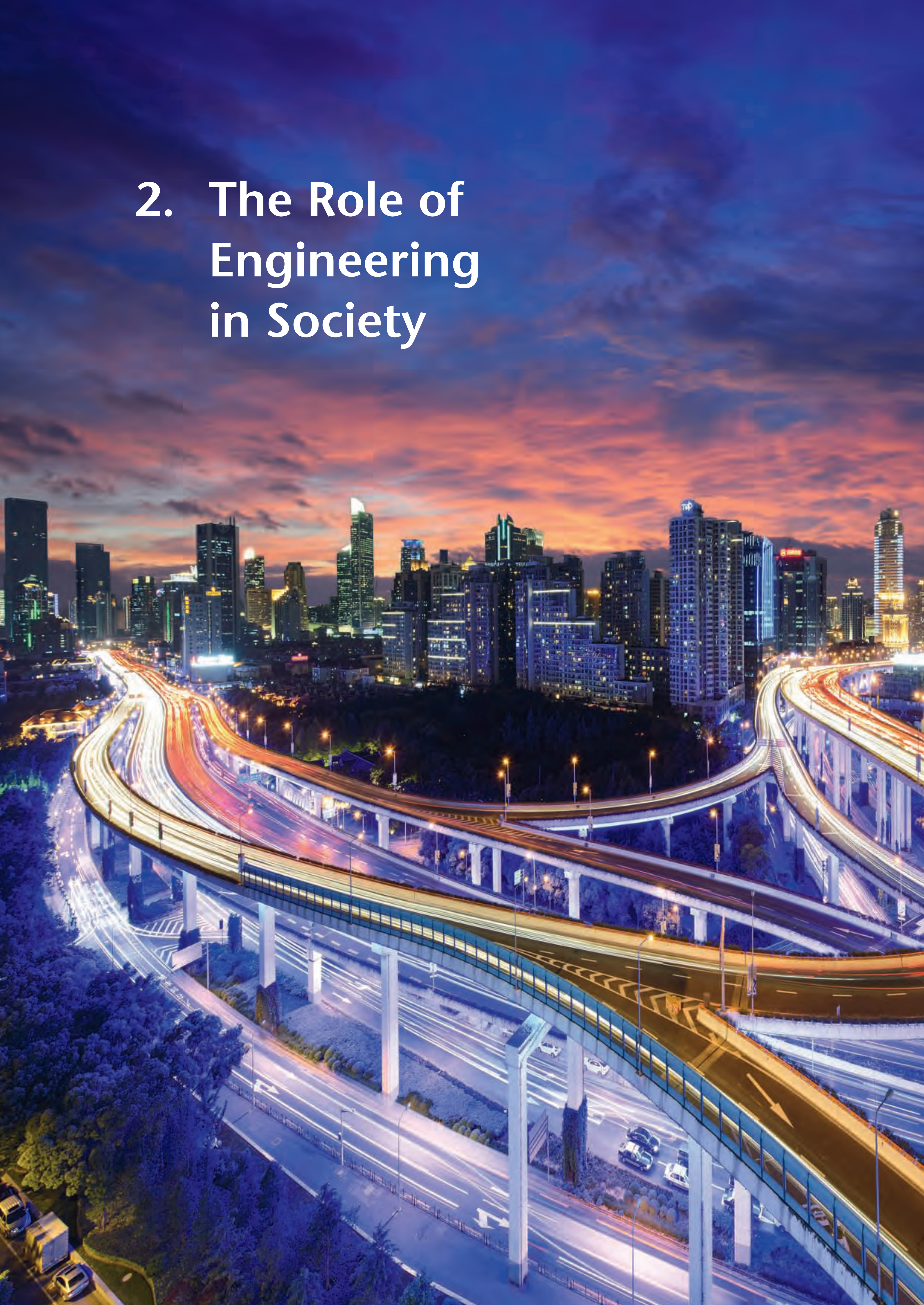
The knowledge explosion has, of course had a major impact upon engineering education. It has led to the extension of programs, increasing depth of consideration as students are taken toward the frontiers of knowledge and expansion in the detail that must be addressed by students. It has also resulted in greater specialisation within engineering education programs and created significant problems in deciding the most appropriate content. However, these developments have caused engineering education programs to be considered to be difficult and demanding. It is therefore a most appropriate time to be considering curriculum appropriateness, effectiveness and design, especially as the challenges which they entail can cause engineering education courses to be difficult and consequently less attractive.

The information technology revolution does, however, provide some tools for utilisation in engineering education programs that can be of considerable benefit to students and staff. They have not yet been fully utilised. It is imperative that they be used to facilitate the successful development of the next generation of engineers. The development of information technology should influence what is included in engineering programs, while also providing tools to assist the learning of the students. It should also change the role that staff are required to play in assisting students to develop their professional competence.

Engineering education is not only about developing the understanding and knowledge of students; it is also essential to develop the capabilities that are necessary for graduates to be able to act as responsible and effective members of the engineering profession within their community. In the information technology age, our communities all depend on their engineers to provide innovative and appropriate solutions to enable the efficient, safe, effective, appropriate and responsible application of technology to meet the community's needs. This is an important responsibility. It should challenge our young people to become engineers if they are seeking a socially responsible way to contribute to their community's welfare. We are also aware that this must be achieved while ensuring that the technological solution chosen is also safe, economical, appropriate and environmentally sustainable.

When all these factors are considered it is apparent that engineers exercise considerable responsibility on behalf of their society. Consequently engineering education needs to be appropriate to the challenges faced by this essential and highly important profession. However engineering education has not responded as rapidly as is necessary. It is still to implement the transformation that is required to enable the next generation of engineers to effectively operate within this changing profession. It is the objective of the authors to assist those who wish to progress such a transformation of engineering education, by providing some insight into the what, why and how of the necessary actions that can achieve transformation in the following sections.

2. The Role of Engineering in Society



2.1 What is Engineering

It is widely accepted that engineers are key figures in the material progress of the world. It is no exaggeration to say that modern society and cities in particular would be quite impossible without the engineering infrastructure that provides water, food, transport, power, shelter, communication and that removes wastes. It is engineering capability that translates the potential value of science into tools, resources, energy and systems for the service of our societies.

There are many descriptions of Engineering. It has been defined in [1] as "the field or discipline, practice, profession and art that relates to the development, acquisition and application of technical, scientific and mathematical knowledge about the understanding, design, development, invention, innovation and use of materials, machines, structures, systems and processes for specific purposes". Wikipedia gives a widely acceptable definition of engineering "as the discipline, art, profession of acquiring and applying technical, scientific and mathematical knowledge to design and implement materials, structures, machines, devices, systems and processes to safely realise a desired objective or outcome." Engineering is commonly described in terms of problem solving through the application of science, mathematics and/or technology.

Engineers regularly deal with complex problems that cannot be resolved without in-depth technical knowledge. This knowledge may be at the forefront of the discipline or be wide-ranging across a number of disciplines. They could be problems that do not have obvious solutions, or have conflicting requirements, and necessitate fundamental and creative design considerations. The problems will typically have numerous parameters and constraints that must be considered in developing and implementing an appropriate solution.

It is necessary to define engineering, and what constitutes an engineer, because it is a profession which requires registration as evidence of competency to practice, in at least some of its various fields, in many countries. This is the responsibility of Professional Engineering Organisations that have been given legal status.

Additionally, because of the international mobility of engineers and their participation in multi-national projects, it has been considered necessary and appropriate to develop some international agreement on the standards that are necessary for the accreditation of engineering education programs and the registration of professional engineers. The process commenced in 1989 with the participation of the Professional Engineering Institutions or Organisations in: Australia, Canada, Ireland, New Zealand, United Kingdom and the United States of America forming what is called the Washington Accord. Subsequently Chinese Taipei, Hong Kong, China, Japan, Korea, Malaysia, Singapore and South Africa have also become Signatories to this reciprocal agreement. Currently Germany, India, Pakistan, Russia, Sri Lanka, Turkey have been accepted as Provisional Members, but have not yet been accepted as Signatories. The process has established standards, expressed in terms of professional competency profiles and graduate attributes, for each of the three categories of employment in the engineering industry: Professional Engineers, Engineering Associates and Engineering Technicians. The graduate attributes are required to be met by graduates exiting an accredited university program to enable entry to the profession as a graduate engineer and the professional competency standards are required to be met approximately 5 years later when each individual is eligible to apply for professional registration. The three Accords are:

- The Washington Accord for Professional Engineers
- The Sydney Accord for Engineering Associates, and
- The Dublin Accord for Engineering Technicians

As this report is focussed upon the education of professional engineers the Washington Accord is of major importance and is considered in detail in Section 3.1.

2.2 What do Engineers do?

The work of professional engineers involves the application of advanced skills in analysis and knowledge of science, technology, management and social responsibility to problem solving, design and development in various fields [12]. This may encompass advanced design and research, development of systems and products, manufacturing and field work, analysis and evaluation, computation and simulation, documentation and communication, supervision and evaluation, implementation and commissioning. It usually involves working in or leading teams and responsibility for co-ordination with experts in other fields. Responsibilities for supervision and management usually evolve as their career progresses. Engineers need to be innovative, creative, informed and responsible to develop the best possible solutions. Engineers are frequently required to make balanced judgements between the conflicting requirements of design refinement, performance, delivery time, safety, cost, risk, and environmental impact.

The Royal Academy of Engineering (RAE) in its consideration of engineering graduates of the future [13] suggests that they will have the following three roles:

- The engineer as a *specialist*, which recognises the continued need for engineers who are technical experts of world class standing,
- The engineer as an *integrator*, which reflects the need for engineers who can operate and manage across boundaries be they technical or organisational in a complex business environment,
- The engineer as a *change agent,* which highlights the critical role engineers must play in providing the creativity, innovation and leadership to shape industry and society in uncertain times.

The engineer's detailed technological knowledge in their specific specialisation is a key factor in their ability to undertake these roles. This is a critical factor in their selection for a particular role in an organisation, but their personal attributes and capabilities are also critical determinants of their capacity to perform that role.

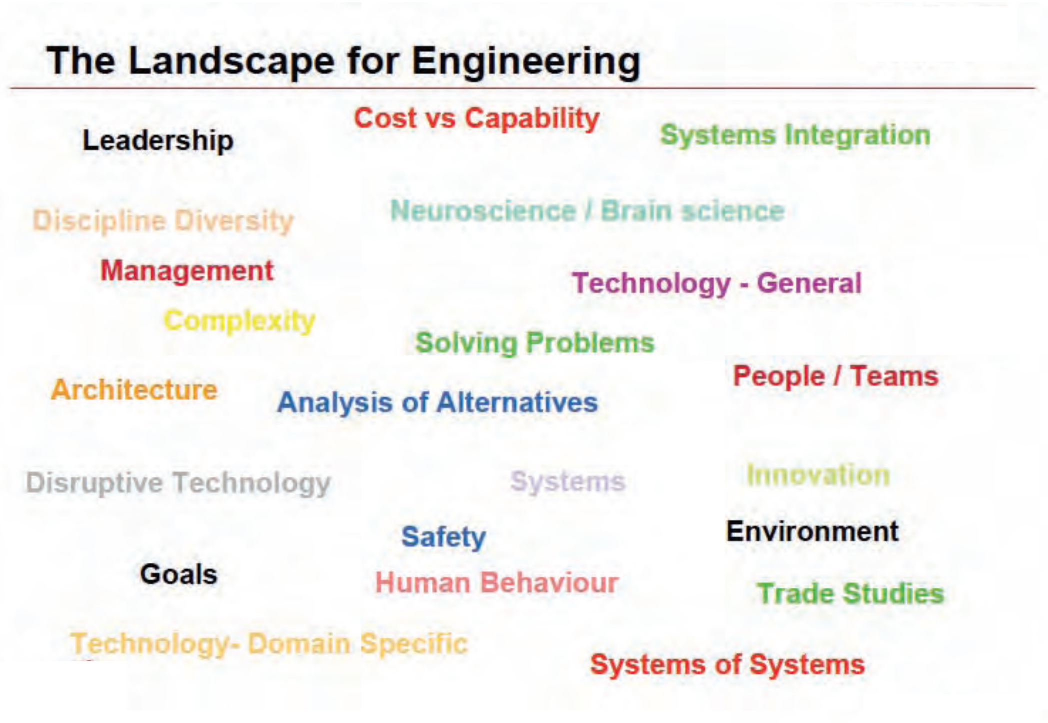


Figure 1: The Landscape for Engineering.

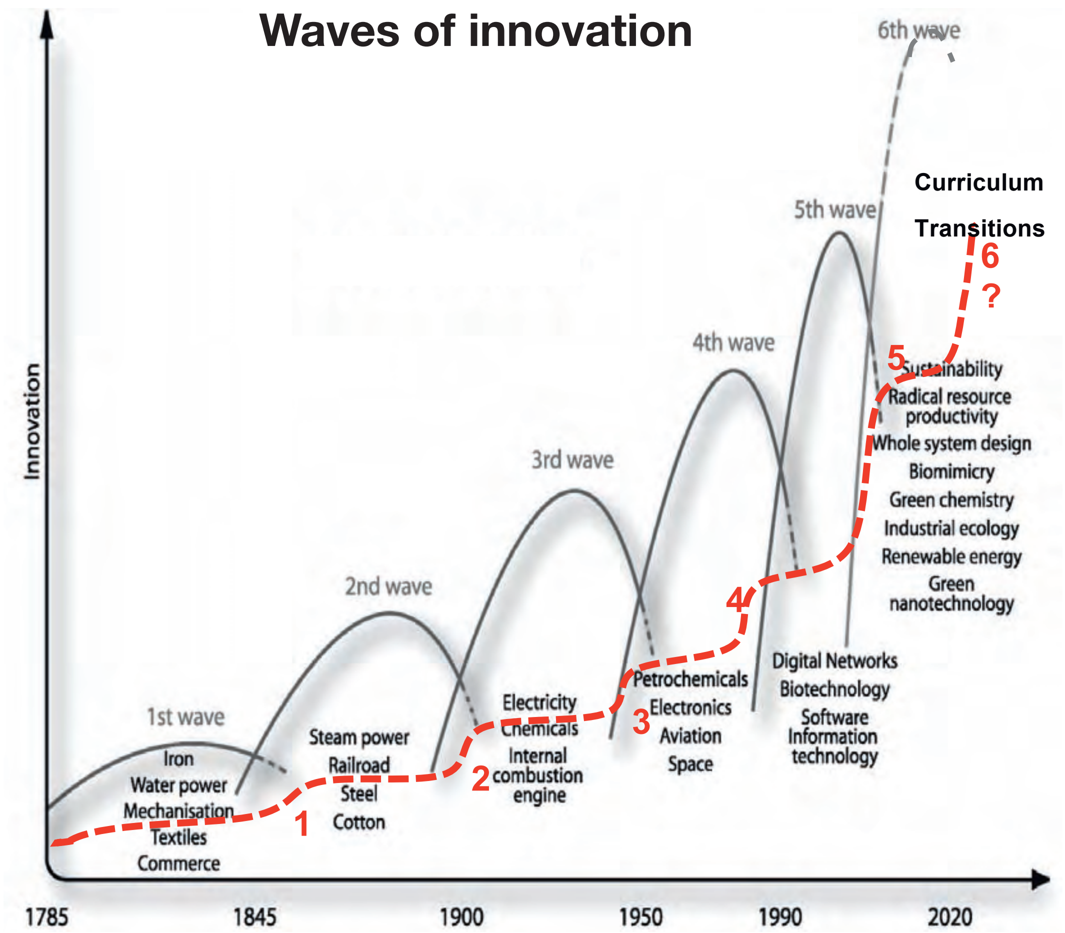


Figure 2: Waves of Innovation [17].

Engineers can be involved in a range of activities that include [14]:

- Research & Development
- Innovation
- Contract Preparation
- Design & Manufacture
- Market Assessment
- Tendering
- Design Development
- Installation & Commissioning
- Commercial Production
- Maintenance & Testing
- Computer Aided Drawing
- Asset Management
- Specification
- Decommissioning & Disposal
- Project Management
- Technical Sales & Marketing

The diversity of interacting factors and issues that cause the activities and responsibilities of an engineer in a large organisation to become quite complex, is shown dramatically in Figure 1, and is provided by courtesy of Raytheon Australia [15].

The breadth of engineering activity viewed from a different perspective is encapsulated by the acronym CDIO [16], which stands for the processes of: CONCEIVING-DESIGNING-IMPLEMENTING-OPERATING. These processes are an integral component of all engineering projects. There is also a post-operating phase relating to decommissioning which is an engineering responsibility. CDIO was first conceived as a vehicle for encouraging new educational frameworks that more adequately address the various phases of engineering activity. It is an approach that has been adopted by many educational institutions and is discussed in Section 4.6.5.

2.3 The Scope of Engineering

As technology has advanced, the breadth of engineering activity has exploded becoming a critical element in the operation and advancement of all societies and countries. There have been successive waves of technology development in the 19th and 20th centuries that have progressively increased the scope on engineering activity, its fields of influence, and consequently its impact upon society. Engineering has changed dramatically in this period and the rate of change has increased further in the 21st century. There is no reason to believe that the rate of change will diminish in the foreseeable future. The successive waves of innovation that have influenced technology development are depicted schematically in Figure 2.

These developments have been reflected in the specialisations of engineering courses expanding from Military & Civil Engineering in the 19th century to now extend their involvement to include the fields of:

- Energy
- Manufacturing
- Mining
- Medical
- Water
- Defence
- Infrastructure
- Development
- Transport Systems
- Transport Vehicles
- Environmental Sustainability
- Construction
- Systems
- Innovation
- Communications
- Computers

This list of major areas of activity of engineers represents functions that are essential for the operation of any country or community. All are dependent upon engineering knowledge to apply technology, although the complexity of the technology may differ.

2.4 How has the Role Changed over the last 50 years?

The pace of innovation has accelerated over the last century. Scientific discovery and understanding facilitate technology development and application, which also facilitates scientific discovery and understanding. This mutual interaction has led to an explosive growth of technology application in the twentieth century which appears to be continuing to accelerate. Our expanded understanding of technology is rapidly applied to deliver significant benefit to communities and individuals. Innovations that are more efficient, more economical or lead to improved performance have been rapidly developed and implemented. These become the technology of our communities through the expertise of engineers until further improvements are possible or an alternative technology is applicable. The nature of technological change is that it proceeds ever more rapidly as it feeds off itself.

Whilst the major streams of engineering, and hence engineering education, became organised into Civil, Mechanical, Electrical and Chemical in the 20th century, additional fields have progressively evolved and the courses now available include the following wide range of specialisations:

- Aeronautical
- Automotive
- Agricultural
- Avionics
- Biomedical
- Chemical
- Civil
- Communication
- Computer
- Electrical
- Electronic
- Environmental
- Geotechnical
- Industrial
- Information
- Manufacturing
- Materials
- Mechanical

- Mechatronics
- Mining
- Molecular
- Microelectronic
- Nanoengineering
- Nuclear
- Process
- Systems
- Structural
- Software
- Railway
- Transportation
- Vehicle
- Acoustic

From this perspective the enormous scope of engineering technology can be readily envisaged. It is also apparent that the rapid expansion of technology continues to produce new engineering specialisations. As a consequence of this expansion, most engineers have been required to develop expertise in some sub-set of engineering activity and capability. However a parallel development has been the broadening of the range of technologies that influence the implementation of a typical engineering project. The development of a vehicle, for example, involves many disciplines including: engines, fuels, electrics, sensors, control, structure, mechanical, information processing and display, materials, stability, manufacture, environment, acoustics and ergonomics. These complex multi-disciplinary projects require a systems approach to co-ordinate the teams that are essential for successfully integrated solutions. It requires engineers to be simultaneously specialists and generalists.

Technology development has enhanced and accelerated the innovation process and the scope of technology applications over the last century. For example; the understanding of materials has been accelerated by the improvement of analytical instrumentation for their examination and characterisation. The improved materials then flow into manufacturing, construction, aeronautics, transport, and other areas.

The development which has had most impact on the rapid advancement of engineering over the last 50 years is the digital computer (wave 5 in Figure 2). It was made possible by the invention of the transistor in 1948 and the first integrated circuit in 1960. The microelectronics revolution has progressed in a remarkable manner, following the growth rate predicted by Moore's Law of a biennial doubling of device count per integrated circuit, to well beyond what were considered the limits of technical feasibility. Now an integrated circuit can contain more than 10 billion components on a single chip. This has been accompanied by massive cost reductions per device that have accelerated their uptake. It has also created a most significant shift in the technology of signal processing from analogue to digital formats. It is the most significant technology advance that has ever been experienced. It has changed the way that business functions, our communication options, and our modes of entertainment. It has led to the ubiquitous personal computer, the mobile phone and the internet. It is changing society. It changes how we work, communicate and relate. It changes how we learn. It is important to remember that the information technology revolution is still at a relatively early phase of its development and potential impact. It will continue to change our societies, how we live, how we operate and how we interact. Additionally almost all our devices, facilities, technological equipment and systems will be progressively redesigned as information technology makes available the possibility of more intelligent and capable facilities at lower cost by providing new ways of measuring, monitoring and controlling to achieve performance enhancements. Engineers are essential to implement the required innovations.

The computer revolution has created new fields of engineering. Additionally it has now influenced all other fields of engineering. The continuing development, growing power, and increasing effectiveness of computers will continue to revolutionise the way engineering problems are solved and to change the most appropriate solution for many situations. It has enabled us to undertake tasks which were previously impossible. The new fields of technology include: computer engineering, software engineering and microelectronics. Fields that have been revolutionised include: instrumentation, communications, robotics, systems and nanotechnology. However all fields have been changed by computers through modelling, instrumentation, simulation, computation and control.

Software now exists for the solution of all complex engineering analysis problems. Sensors can be combined with computers to continually monitor and control complex systems. Developments have enabled personal and portable computers, mobile telephones and communication devices that are small, convenient, and economical while being powerful enough to change the way individuals and organisations operate. They have permitted activities of previously impossible complexity to be undertaken. Examples include space exploration and communication satellites, medical imaging, astronomical telescopes, defence equipment, micro-machines, robotics, personal computers, global positioning systems, environmental monitoring, massive databases, internet and global communications. They have provided previously unimagined routine capability to engineers through computer aided simulation, calculation, design, drafting and machining, by implementation, control and project management software, and by the provision of collaborative networks to access and share complex information.

Computers have changed the way the engineering profession and engineering organisations operate. There is a computer on every engineer's desk. It is usually their input and output device and their design tool. It gives quick access to public, organisational, professional and private information. Increasingly computers are wireless and portable, while massive computers share information via high speed networks. They will have access to more accurate data, more extensive information, enhanced instrumentation, improved monitoring, and a wider range of more effective tools with which to undertake their roles. The computer revolution is not yet complete, although it is well advanced.

Engineering projects, as a result of the computer revolution, utilise more complex technology to address the data, control, information, recording, protection, safety, maintenance and communication aspects of projects. This places more emphasis on the system issues and has caused many projects to require a greater diversity of engineering skills to address the system and high technology issues.

Ironically, even though they are information based institutions, universities in general, and engineering education institutions in particular, have not fully grasped the opportunities presented by the computer revolution. Information technology provides the opportunity to utilise different approaches to improve the effectiveness of their educational processes. This will be pursued further in Section 5.5.

The developing global commitment to the minimisation of global warming by achieving planned reductions of greenhouse gas emissions is progressively moving towards universal support. An understanding of environmental sustainability in engineering projects is already a component of the charter of responsibilities for engineers and it has become a rapidly expanding field of engineering education. It will become a large field of activity because of the need to develop innovative new technology to provide solutions to many of the current problems such as the generation of clean energy. The environmental issues must be addressed and resolved in every engineering project. Environmental and societal issues require engineers to design and implement both local and global solutions.

Engineering now requires the solution to problems, as identified by society, to be achieved by the application of the most appropriate available technologies. This task will lead to the most appropriate solution differing according to the particular circumstances. It is important that engineers remain focussed upon addressing effectively and responsibly the needs of their community when selecting the appropriate technology for the project they are employed to deliver.

Both the scope and the scale of the services required by societies have expanded dramatically as they have become more dependent upon technology. The engineering services required by our communities include: buildings (structures, foundations, materials, services, environment), water (dams, pipelines, purification, irrigation, drainage, waste, sewage, environment), electricity (generation, transmission, distribution, control, environment), transport (roads, vehicles, bridges, manufacture, fuel, safety, ships, ports, aeroplanes, airports, railways, trains, environment), communication (telephone, data, television, satellite, cable, radio, digital networks, computers, personal communication devices). The list goes on to include services for medical, defence, agriculture, food, manufacturing, government and commercial applications.

The role of engineering extends well beyond concept and design. It extends to estimation, research, development, manufacture, construction, installation, evaluation, maintenance, and decommissioning. It also includes issues of community benefit and welfare, ethics, environment, efficiency, cost minimisation, financial management, supervision and organisational management. One area where engineers should be more involved, but their influence has been diminished as government has passed the responsibility for projects to the private sector, is the feasibility, planning and cost estimation of major infrastructure projects for government. These projects are often undertaken without adequate engineering input in the project conceptualisation phase. In many countries, government effectiveness would be enhanced by an increase in the engineering capacity of their staff.

With the increasing scale of many engineering projects it is an inevitable outcome that they become multidisciplinary. The projects then become system projects and an increasing role for many engineers becomes that of system engineering. They will work in teams with other engineers who are required to deal with the specialist issues. Another changing trend is for projects to extend from just requiring design and construction, to include responsibility for operation, maintenance and possibly decommissioning. These changes broaden the skill-set required of engineers and consequently the nature of engineering education that should be provided.

Engineering as a profession is undergoing continual change. Projects may be undertaken by international engineering corporations utilising teams which operate in several countries (and often in different time zones) with interaction and coordination facilitated by electronic communication to speed up the design/development phase of the project. As a result of the "commoditising" of many design tasks, much of the design can be "outsourced" and the major component of the project becomes the management of design co-ordination and the people, materials, equipment, tasks, schedules and costs involved. Both design and implementation are complex system engineering problems. From these considerations it can be seen that this is a time of transformation in engineering practice as the issues and the possibilities have become more complex.

2.5 How does Engineering differ from Science?

The definition of Science (from the Latin *scientia*, meaning "knowledge") given by Wikipedia is : "an enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the world". An older and closely related meaning, still in use today, is that of Aristotle, for whom scientific knowledge "was a body of reliable knowledge that can be logically and rationally explained".

These concepts emphasise that science is focussed upon the creation of understanding of the physical world through experimental testing of hypotheses, leading to the establishment of principles that describe behaviour in various situations and can be used to predict behaviour in related conditions. The traditional sciences are physics, chemistry, mathematics, biology and geology. Applied science relates to the application of these understandings to achieve practical outcomes. Applied scientists seek to utilise the scientific insights that they have established for some useful outcome.

Science is clearly different from engineering; the former aims to extend our understanding, while the latter is endeavouring to solve problems and by implementation of the solution designed. Science is directed towards discovery and often the issues that it investigates are matters of considerable importance, with community benefits flowing from the insights gained. Engineering is directed towards the achievement of particular required outcomes and while this may follow established practice in many situations, it may also involve creative innovation. Engineers are the major contributors to the innovation processes that are continually required in our developing societies. As innovators, engineers are the designers and experimenters that conceive new and effective solutions to technological problems, programs and projects. As implementers, engineers are the important contributors to the conception, assessment, planning and costing of the major projects required by our various communities. Engineers are the key innovators upon whom our societies are critically dependent.

A practical example which illustrates this difference between the role of scientists and engineers is environmental sustainability. Scientists are developing the understanding of the global warming process through extensive measurements, data analysis and computer modelling. This is clearly important to establish the causes, the positive and negative factors that determine the outcomes, the rate of change created by the significant variables in the process, and their interaction. The role of engineers is to develop solutions which create sustainable energy sources, water supplies, buildings, infrastructure, transport systems, waste management and processing facilities, manufacturing and agricultural processes to reduce the greenhouse gas emissions to long-term sustainable levels in all the activities of our civilisations. This is a major additional responsibility for all engineers. It is also a reason to be concerned about the global shortage of engineers and to ensure that sustainable engineering is a major component of all engineering education.

As explained in Section 2.1, engineering will utilise the understandings provided by science to develop the most appropriate solution to the problems upon which it is focussed. Consequently there is a partnership between these two distinct professions. Engineers apply the knowledge established by scientists to solve practical problems. While doing this, engineers may work in cooperation with and alongside scientists in the same team, to achieve the objectives of a development program. This is most likely to occur in projects that are applying rapidly advancing technologies. For these reasons it is of fundamental importance that engineers have an adequate understanding of the science and mathematics that is relevant to the problems that they are attempting to solve. However engineering is not just applied science, as it has a much broader role and operational philosophy. Engineering is also applied economics and applied social and environmental ethics.

Engineering is always under pressure to not only provide effective solutions to the issues that depend on technology, but to provide them quickly, more economically, fulfilling their required function more effectively, operating safely for longer, creating no long term waste, requiring minimal maintenance, demonstrating social responsibility, and having the least possible environmental impact. It provides an exciting and rewarding career for those young people who are seeking to undertake something worthwhile for the future of their various societies. Understanding of this important responsibility and the exciting challenge offered by an engineering career needs to be more effectively conveyed to school students if we are to develop the number of engineers that are required.

Following in the tradition that universities awarded either Arts degrees or Science degrees, it has been the practice in some universities to award a Bachelor of Science degree to graduates of an engineering degree program. This seems to be an inappropriate practice as it is confusing and misleading for potential students. There are some universities, eg [18], that have used a Bachelor of Arts degree as the qualities required of engineers tend to be more predominantly aligned with the liberal arts traditions than science. However, it still seems preferable and reasonable to expect professional engineering degrees to be designated as Bachelor (or Master) of Engineering.

2.6 Illustrative Engineering Projects

Some of the challenging and exciting engineering projects that have captured the public imagination include:

- space ships that can take people safely to the moon
- lunar exploration by robotic vehicles
- satellite communication and global position systems
- personal computers and networks
- mobile telephones and their extensive capabilities
- integrated circuit technology
- high speed trains

- drilling platforms for deep-sea oil or gas wells
- aeroplanes for fast and comfortable long-distance travel
- robots for manufacture or agriculture
- sustainable generation of electricity
- skyscrapers and complex building structures
- major dams and water systems
- accelerators for examining sub-atomic particles

However there are many more that we take for granted as they increasingly become an integral component of our societies. These include:

- motor vehicles and road infrastructure
- mass transport systems
- ships and ports
- world wide web
- ipads
- efficient personal transport and infrastructure
- medical radiation scanners
- non-invasive surgery
- replacement body parts
- security systems
- advanced manufacturing
- monitoring systems for weather and related parameters
- information systems
- entertainment systems
- chemical processing plants
- electricity generating plants and distribution networks
- mining and tunnelling equipment
- communications infrastructure
- water purification and desalination plants
- materials development and purification
- agricultural automation.

These all represent areas of engineering creativity and innovation that require investigation, experimentation, design, development and evaluation to bring ideas to the point of feasibility. There is then the extensive task of engineering the implementation that involves proof of concept, sustainability, social implications, business model evaluation, marketing, manufacture, distribution, maintainability and servicing and safe disposal at the end of its serviceable life. There are many diverse engineering roles in the complex processes that are associated with these activities that have become an essential component of life in the 21st century. Consequently there are numerous exciting and fulfilling aspects of engineering that students should be introduced to, so that during their engineering education program they can develop the range of competencies essential to enable them to effectively participate in the extension of engineering's contribution to society.

Recently a panel consisting of engineers, scientists and futurists considered what it believed were the Grand Engineering Challenges that would most benefit the world if they were solved. Their list of 14 was endorsed by USA National Academy of Engineering (NAE) in 2008 [19]. These items, which indicate some of the important challenges that lie ahead in the careers of future engineering graduates, are:

- Make solar energy affordable
- Provide energy from nuclear fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalised learning
- Engineer the tools for scientific discovery.

3. International Standards and the Goals of Engineering Education

3.1 The Washington Accord

The International Engineering Alliance developed an Accord Agreement [20], initially in 2002 and revised in 2009, is a binding agreement for the signatory countries (refer to section 2.1) which needs to be addressed by intending members. It has become the de facto standard for engineering education in a world where engineering is an increasingly international activity. It is known as The Washington Accord and explains that: "The fundamental purpose of *engineering education* is to build a **knowledge base and attributes** to enable the graduate to continue learning and to proceed to formative development that will develop the competencies required for independent practice. The second stage, following after a period of formative development, is *professional registration.* The fundamental purpose of formative development is to build on the educational base to develop the competencies required for independent practice in which the graduate works with engineering practitioners and progresses from an assisting role to taking more individual and team responsibility until competence can be demonstrated at the level required for registration. Once registered, the practitioner must maintain and expand competence."

This is a very important statement. Firstly, because it places the responsibility for delivering the specified knowledge base and graduate attributes required to be an engineer entirely upon the university, its engineering education staff and the organisational unit. There is no alternative route to enter the engineering profession and the objectives to be met by university graduates are clearly specified. Secondly, because there is also a continuing education role that is the shared responsibility of the graduate engineer, their employer and preferably their university, to reach professional registration level. It is therefore, essential for universities to plan their undergraduate programs in the context of this policy and desirable that they also plan their postgraduate coursework programs to facilitate the formative development of engineers seeking registration.

The specified knowledge base and graduate attributes become the specification of the minimum standards that should be achieved by every student when they have completed their engineering education experience and qualified for the degree of the university. The process of ensuring that this is achieved is the Program Accreditation Process which must be undertaken periodically by each National Engineering Association that is a signatory to the Washington Accord. They should therefore become the educational objectives of every engineering education program in all signatory (or intending signatory) countries. Since engineering is an activity that often requires large international companies to provide the expertise and experience essential to undertake large engineering projects, it can be argued that the Washington Accord Graduate Attributes would form useful objectives for the formation of engineers in all countries. This would ensure that engineers from all countries could operate together in multi-national teams on international projects.

Since these statements [21] from the Washington Accord hold this significance, then it is only appropriate that we examine them very closely. To avoid misunderstandings they are quoted verbatim below.

"*Graduate attributes* form a set of individually assessable outcomes that are the components indicative of the graduate's potential to acquire competence to practise at the appropriate level. The graduate attributes are exemplars of the attributes expected of graduate from an accredited programme. Graduate attributes are clear, succinct statements of the expected capability, qualified if necessary by a range indication appropriate to the type of programme.

The attributes of Accord programmes are defined as a *knowledge profile,* an indicated volume of learning and the attributes against which graduates must be able to perform. The requirements are stated without reference to the design of programmes that would achieve the requirements. Providers therefore have freedom to design programmes with different detailed structure, learning pathways and modes of delivery.

The Knowledge Profile of an Engineer:

- A systematic, theory–based understanding of the **natural sciences** applicable to the discipline (e.g. calculus-based physics).

- Conceptually-based **mathematics:** numerical analysis, statistics and formal aspects of computer and information science to support analysis and modelling applicable to the discipline.
- A systematic, theory–based formulation of **engineering fundamentals** required in the engineering discipline.
- Engineering **specialist knowledge** that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.
- Knowledge that supports **engineering design** in a practice area.
- Knowledge of **engineering practice** (technology) in the practice areas in the engineering discipline.
- **Comprehension** of the role of engineering in society and identified issues in engineering practice in the discipline; ethics and professional responsibility of an engineer to public safety;
- Engagement with selected knowledge in the **research literature** of the discipline.

A program that builds this type of knowledge and develops the attributes listed below is typically achieved in 4 to 5 years of study, depending on the level of the students on entry. Each graduate should possess the attributes below.

The Graduate Attribute Profile of an Engineer:

1. **Engineering Knowledge:** Able to apply knowledge of mathematics, science, engineering fundamentals and an engineering specialisation to the solution of complex engineering problems.
2. **Problem Analysis:** Can identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
4. **Investigation:** Conduct investigations of complex problems using research based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
5. **Modern Tool Usage:** Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations.
6. **The Engineer and Society:** Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.
7. **Environment and Sustainability:** Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
9. **Individual and Team Work:** Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.
10. **Communication:** Communicate effectively on complex engineering

activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project Management and Finance:** Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change."

3.2 Implications of the Washington Accord's Graduate Attributes

These policies represent the most comprehensive and thoroughly developed statements detailing what should be the objectives of, and the outcomes delivered by, engineering education. They have been developed and adopted by the national engineering associations in many countries. These bodies have the responsibility for accreditation of the various engineering programs delivered in their respective countries. These policies were first developed in 1989 and it is the third version published in 2009 which is quoted above. Their adoption by 13 countries, with an additional 6 seeking to conform, places the engineering profession in a unique position to be able to move towards multi-national acceptance of the qualifications of engineers. This is commendable when there are so many multi-national engineering companies and multi-national engineering projects. The adoption of multi-national standards in engineering is a very desirable objective.

Consequently these 12 graduate attributes, in the context of the outlined knowledge profile, should become the goals of the engineering programs delivered in the signatory and provisional countries. It is considered that they also would be desirable goals for all other countries that are seeking to reach an international standard in engineering education. When these attributes are examined as goals of engineering education programs the following observations can be made. They:

- relate well to what an engineer does and how they operate,
- place significant emphasis on dealing with complexity,
- consider science and mathematics as tools,
- do not specify or emphasise the depth of knowledge required explicitly,
- require familiarity and capability with IT,
- emphasise the importance of personal attributes which are essential for an engineer,
- expect effectiveness in a discipline area, but also a breadth of engineering knowledge,
- value the consideration of others in society,
- require graduates to address a significant breadth of issues outside of engineering,
- expect up-to-date information & knowledge in the specialist field,
- place significant emphasis on environmental issues and sustainability,
- expect a capability for independent learning to be developed,

- require all graduate attributes to be developed, not a selection from those listed,
- apply to engineering education programs in any country, and
- provide a benchmark for the consideration of the transformation of engineering education.

If we examine them more closely, they can be placed in the following classification:

Technical understanding:
1. Knowledge
2. Analysis

Technical engineering capabilities:
3. Design
4. Investigation
5. Tool use

Community responsibilities:
6. Society
7. Environment

Personal capabilities:
8. Ethics
9. Individual & team member
10. Communications
11. Project management
12. Life-long learning

This classification shows that five graduate attributes are related to technical engineering knowledge and its application, while seven are related to broad knowledge, skills, capabilities and attributes that are considered to be essential for an engineer to be able to perform effectively in the 21st Century.

However engineering education programs and curricular are generally organised around and focussed upon delivering The Knowledge Profile component, as they have been for most of the last 50 years. The Graduate Attribute Profile tends to receive peripheral attention in program design and delivery as if it is something that will occur incidentally through involvement in design projects or other course experiences. The development of personal attributes is not usually given the direct attention that the Washington Accord requires. ***Program design and delivery should be focussed upon the development and realisation of the Washington Accord Graduate Attributes.*** This is a major challenge for universities as very few engineering education programs are sufficiently, and explicitly, focussed upon the development of the personal attributes of their students and hence their graduates.

As the Washington Accord attributes are essential attributes that must be possessed by each graduate completing the program, it follows that they must be subject to assessment. Without such assessment it is not possible to assure that they have been realised by each graduating student. Also, without assessment they will not receive attention which is commensurate with their importance. A direct relationship between the Washington Accord attributes and program design and assessment has not yet become the commonly accepted practice in engineering education. Although the engineering programs of universities are subject to accreditation, by their respective National Professional Engineering Institutions or Associations, it must be concluded that the assessment of the achievement of the graduate attributes by the universities has not yet become an essential requirement for course accreditation. This highlights a significant deficiency in the course accreditation process which will be considered further in Section 6.6.

The objectives and emphasis of the majority of engineering education degree programs are content related. This relates well to the development of the Knowledge Profile of an Engineer as specified in the Washington Accord. However this approach over-emphasises one dimension of an engineer's development. Much of the criticism of current engineering education programs is related to the over emphasis of content (or knowledge components) and the inadequate emphasis on personal attribute (or capability) development. It has given rise to the many calls for transformation and it will be addressed in detail in many of the following sections of this report.

3.3 How have Professional Bodies Applied the Washington Accord?

The goals of engineering education programs are of critical importance. With a clear set of agreed policies established for what a university education in engineering should achieve to comply with the Washington Accord, it is therefore important to consider their operation and impact at the implementation phase. This is the responsibility of the various National Engineering Associations which are all independent bodies. They are charged with having equivalent, and not necessarily identical, outcomes. This is essential because there are national variations in educational systems, entry standards and the duration of programs. Each has developed policies, tailored to their country, for the accreditation of their universities. With program objectives being of such importance, the assessment criteria which are specified for the accreditation of universities in typical member countries is quoted in detail. The selected countries are United Kingdom, Australia and USA.

3.3.1 United Kingdom

In the United Kingdom the responsibility for accreditation is accepted by the Engineering Council UK [22]. Following a statement of the General Learning Outcomes that they expect of graduates from an accredited program leading to a Bachelor (Honours) award in Engineering, they specify the Specific Learning Outcomes which must be achieved:

Underpinning science and mathematics and associated engineering disciplines:

- Knowledge and understanding of scientific principles and methodology necessary to underpin their education in the engineering discipline, to enable appreciation of its scientific and engineering context, and to support their understanding of historical content and future developments and technology.
- Knowledge and understanding of mathematical principles necessary to underpin their education in their engineering discipline and to enable them to apply engineering methods, tools and notations proficiently in the analysis and solution of engineering problems.
- Ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline.

Engineering analysis:

- Understanding of engineering principles and the ability to apply them to analyse key engineering processes.
- Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modelling techniques.
- Ability to apply quantitative methods and computer software relevant to their engineering discipline, in order to solve engineering problems.
- Understanding of and ability to apply a systems approach to engineering problems.

Design:

Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges and can be used to integrate all engineering understanding, knowledge and skills to the solution of real problems. Graduates will therefore need the knowledge, understanding and skills to:

- Investigate and define a problem and identify constraint including environmental and sustainability limitations, health and safety and risk assessment issues.
- Understanding customer and user needs and the importance of considerations such as aesthetics.

- Identify and manage cost drivers.
- Use creativity to establish innovative solutions.
- Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal.
- Manage the design process and evaluate outcomes.

Economic, social and environmental context:

- Knowledge and understanding of commercial and economic context of engineering processes.
- Knowledge of management techniques which may be used to achieve engineering objectives within that context.
- Understanding of the requirements for engineering activities to promote sustainable development.
- Awareness of the framework of relevant legal requirements governing engineering activities, including personnel, health, safety and risk (including environmental) issues.
- Understanding of the need for a high level of professional and ethical conduct in engineering.

Engineering Practice:

Engineering practice involves the practical application of engineering skills, combining theory and experience, and the use of other relevant knowledge and skills. This can include:

- Knowledge of characteristics of particular materials, equipment, processes or products.
- Workshop and laboratory skills.
- Understanding of contexts in which engineering knowledge can be applied. (e.g. operations and management, technology, development, etc.)
- Understanding use of technical literature and other information sources.
- Awareness of nature of intellectual property and contractual issues.
- Understanding of appropriate codes of practice and industry standards.
- Awareness of quality issues.
- Ability to work with technical uncertainty.

Under the 5 major categories there are 26 mandatory Specific Learning Outcomes that are used to enumerate the 8 Knowledge Profile components and the 12 Graduate Attributes specified in the Washington Accord. Analysis shows that some of the Accord Attributes are significantly emphasised (1-6), while, surprisingly, there is no explicit reference to the following three attributes: 9 (individual & team-work), 10 (communication) and 12 (life-long learning).

3.3.2 Australia

In Australia the competency standards for professional engineers are established by Engineers Australia. They have been recently revised [23] to comprise 3 Stage 1 Competencies (Knowledge and Skill Base, Engineering Application Ability, and Professional and Personal Attributes), which are covered by 16 mandatory Elements of Competency. They represent the profession's expression of the knowledge profile, professional engineering abilities and skills, personal values and attitudes that must be demonstrated by graduates at the point of entry to practice. They do provide overall coverage of the Washington Accord Graduate Attributes.

In addition to the 16 mandatory Elements of Competency there are 69 Indicators of Attainment that more explicitly describe the outcomes that are expected to be achieved within each Element. These are intended to advise educational institutions of the standards expected, with the intention of facilitating their assessment of graduate achievements. The concept is good, as it is necessary for academic institutions to translate the more general Elements of Competency into standards to be achieved by their graduates. However the large number and their lack of precise interpretation, detracts from their usefulness [24].

Elements of Competency

1. Knowledge and Skill Base

1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

1.2 Conceptual understanding of the, mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.

1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline.

1.4 Discernment of knowledge development and research directions within the engineering discipline.

1.5 Knowledge of contextual factors impacting the engineering discipline.

1.6. Understanding of the scope, principles, norms, accountabilities and bounds of contemporary engineering practice in the specific discipline.

2. Engineering Application Ability

2.1 Application of established engineering methods to complex engineering problem solving.

2.2 Fluent application of engineering techniques, tools and resources.

2.3 Application of systematic engineering synthesis and design processes.

2.4 Application of systematic approaches to the conduct and management of engineering projects.

3. Professional and Personal Attributes

3.1 Ethical conduct and professional accountability

3.2 Effective oral and written communication in professional and lay domains.

3.3 Creative, innovative and pro-active demeanour.

3.4 Professional use and management of information.

3.5 Orderly management of self, and professional conduct.

3.6 Effective team membership and team leadership.

The Corresponding Indicators of Attainment are:

1.1 Engages with the engineering discipline at a phenomenological level, applying sciences and engineering fundamentals to systematic investigation, interpretation, analysis and innovative solution of complex problems and broader aspects of engineering practice.

1.2 Develops and fluently applies relevant investigation analysis, interpretation, assessment, characterisation, prediction, evaluation, modelling, decision making, measurement, evaluation, knowledge management and communication tools and techniques pertinent to the engineering discipline.

1.3 Proficiently applies advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline.

1.4 (a) IIdentifies and critically appraises current developments, advanced technologies, emerging issues and interdisciplinary linkages in at least one specialist practice domain of the engineering discipline.

(b) Interprets and applies selected research literature to inform engineering application in at least one specialist domain of the engineering discipline.

1.5 (a) Identifies and understands the interactions between engineering systems and people in the social, cultural, environmental, commercial, legal and political contexts in which they operate, including both the positive role of engineering in sustainable development and the potentially adverse impacts of engineering activity in the engineering discipline.

(b) Is aware of the founding principles of human factors relevant to the engineering discipline.

(c) Is aware of the fundamentals of business and enterprise management.

(d) Identifies the structure, roles and capabilities of the engineering workforce.

(e) Appreciates the issues associated with international engineering practice and global operating contexts.

1.6 (a) Applies systematic principles of engineering design relevant to the engineering discipline.

(b) Appreciates the basis and relevance of standards and codes of practice, as well as legislative and statutory requirements applicable to the engineering discipline.

(c) Appreciates the principles of safety engineering, risk management and the health and safety responsibilities of the professional engineer, including legislative requirements applicable to the engineering discipline.

(d) Appreciates the social, environmental and economic principles of sustainable engineering practice.

(e) Understands the fundamental principles of engineering project management as a basis for planning, organising and managing resources.

(f) Appreciates the formal structures and methodologies of systems engineering as a holistic basis for managing complexity and sustainability in engineering practice.

2.1 (a) Identifies, discerns and characterises salient issues, determines and analyses causes and effects, justifies and applies appropriate simplifying assumptions, predicts performance and behaviour, synthesises solution strategies and develops substantiated conclusions.

(b) Ensures that all aspects of an engineering activity are soundly based on fundamental principles – by diagnosing and taking appropriate action with data, calculations, results, proposals, processes, practices and documented information that may be ill-founded, illogical, erroneous, unreliable or unrealistic.

(c) Competently addresses engineering problems involving uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors.

(d) Partitions problems, processes or systems into manageable elements for the purposes of analysis, modelling or design and then re-combines to form a whole, with the integrity and performance of the overall system as the paramount consideration.

(e) Conceptualises alternative engineering approaches and evaluates potential outcomes against appropriate criteria to justify an optimal solution choice.

(f) Critically reviews and applies relevant standards and codes of practice underpinning the engineering discipline and nominated specialisations.

(g) Identifies, quantifies, mitigates and manages technical, health, environmental, safety and other contextual risks associated with engineering application in the designated engineering discipline.

(h) Interprets and ensures compliance with relevant legislative and statutory requirements applicable to the engineering discipline.

(i) Investigates complex problems using research-based knowledge and research methods.

2.2 (a) Proficiently identifies, selects and applies the materials, components, devices, systems, processes, resources, plant and equipment relevant to the engineering discipline.

(b) Constructs or selects and applies from a qualitative description of a phenomenon, process, system, component or device a mathematical, physical or computational model based on fundamental scientific principles and justifiable simplifying assumptions.

(c) Determines properties, performance, safe working limits, failure modes, and other inherent parameters of materials, components and systems relevant to the engineering discipline.

(d) Applies a wide range of engineering tools for analysis, simulation, visualisation, synthesis and design, including assessing the accuracy and limitations of such tools, and validation of their results.

(e) Applies formal systems engineering methods to address the planning and execution of complex, problem solving and engineering projects.

(f) Designs and conducts experiments, analyses and interprets result data and formulates reliable conclusions.

(g) Analyses sources of error in applied models and experiments; eliminates, minimises or compensates for such errors; quantifies significance of errors to any conclusions drawn.

(h) Safely applies laboratory, test and experimental procedures appropriate to the engineering discipline.

(i) Understands the need for systematic management of the acquisition, commissioning, operation, upgrade, monitoring and maintenance of engineering plant, facilities, equipment and systems.

(j) Understands the role of quality management systems, tools and processes within a culture of continuous improvement.

2.3 (a) Proficiently applies technical knowledge and open ended problem solving skills as well as appropriate tools and resources to design components, elements, systems, plant, facilities and/or processes to satisfy user requirements.

(b) Addresses broad contextual constraints such as social, cultural, environmental, commercial, legal political and human factors, as well as health, safety and sustainability imperatives as an integral part of the design process.

(c) Executes and leads a whole systems design cycle approach including tasks such as:

– determining client requirements and identifying the impact of relevant contextual factors, including business planning and costing targets;

- systematically addressing sustainability criteria;

- working within projected development, production and implementation constraints;

- eliciting, scoping and documenting the required outcomes of the design task and defining acceptance criteria;

- identifying assessing and managing technical, health and safety risks integral to the design process;

- writing engineering specifications, that fully satisfy the formal requirements;

- ensuring compliance with essential engineering standards and codes of practice;

- partitioning the design task into appropriate modular, functional elements; that can be separately addressed and subsequently integrated through defined interfaces;

- identifying and analysing possible design approaches and justifying an optimal approach;

- developing and completing the design using appropriate engineering principles, tools, and processes;

- integrating functional elements to form a coherent design solution;

- quantifying the materials, components, systems, equipment, facilities, engineering resources and operating arrangements needed for implementation of the solution;

- checking the design solution for each element and the integrated system against the engineering specifications;

- devising and documenting tests that will verify performance of the elements and the integrated realisation;

- prototyping/implementing the design solution and verifying performance against specification;

- documenting, commissioning and reporting the design outcome.

(d) Is aware of the accountabilities of the professional engineer in relation to the ‘design authority’ role.

2.4 (a) Contributes to and/or manages complex engineering project activity, as a member and/or as leader of an engineering team.

(b) Seeks out the requirements and associated resources and realistically assesses the scope, dimensions, scale of effort and indicative costs of a complex engineering project.

(c) Accommodates relevant contextual issues into all phases of engineering project work, including the fundamentals of business planning and financial management

(d) Proficiently applies basic systems engineering and/or project management tools and processes to the planning and execution of project work, targeting the delivery of a significant outcome to a professional standard.

(e) Is aware of the need to plan and quantify performance over the full life-cycle of a project, managing engineering performance within the overall implementation context.

(f) Demonstrates commitment to sustainable engineering practices and the achievement of sustainable outcomes in all facets of engineering project work.

3.1 (a) Demonstrates commitment to uphold the Engineers Australia – Code of Ethics, and established norms of professional conduct pertinent to the engineering discipline.

(b) Understands the need for 'due-diligence' in certification, compliance and risk management processes.

(c) Understands the accountabilities of the professional engineer and the broader engineering team for the safety of other people and for protection of the environment.

(d) Is aware of the fundamental principles of intellectual property rights and protection.

3.2 (a) Is proficient in listening, speaking, reading and writing English, including:

- comprehending critically and fairly the viewpoints of others;
- expressing information effectively and succinctly, issuing instruction, engaging in discussion, presenting arguments and justification, debating and negotiating – to technical and non-technical audiences and using textual, diagrammatic, pictorial and graphical media best suited to the context;
- representing an engineering position, or the engineering profession at large, to the broader community;
- appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences.

(b) Prepares high quality engineering documents such as progress and project reports, reports of investigations and feasibility studies, proposals, specifications, design records, drawings, technical descriptions and presentations pertinent to the engineering discipline.

3.3 (a) Applies creative approaches to identify and develop alternative concepts, solutions and procedures, appropriately challenges engineering practices from technical and non-technical viewpoints; identifies new technological opportunities.

(b) Seeks out new developments in the engineering discipline and specialisations and applies fundamental knowledge and systematic processes to evaluate and report potential.

(c) Is aware of broader fields of science, engineering, technology and commerce from which new ideas and interfaces may be may drawn and readily engages with professionals from these fields to exchange ideas.

3.4 (a) Is proficient in locating and utilising information – including accessing, systematically searching, analysing, evaluating and referencing relevant published works and data; is proficient in the use of indexes, bibliographic databases and other search facilities.

(b) Critically assesses the accuracy, reliability and authenticity of information.

(c) Is aware of common document

identification, tracking and control procedures.

3.5 (a) Demonstrates commitment to critical self-review and performance evaluation against appropriate criteria as a primary means of tracking personal development needs and achievements.

(b) Understands the importance of being a member of a professional and intellectual community, learning from its knowledge and standards, and contributing to their maintenance and advancement.

(c) Demonstrates commitment to life-long learning and professional development, personal, career and organisational goals and objectives.

(d) Manages time and processes effectively, priorities competing demands to achieve personal, career and organisational objectives

(e) Thinks critically and applies an appropriate balance of logic and intellectual criteria to analysis, judgment and decision making.

(f) Presents a professional image in all circumstances, including relations with clients, stakeholders, as well as with professional and technical colleagues across wide ranging disciplines.

3.6 (a) Understands the fundamentals of team dynamics and leadership.

(b) Functions as an effective member or leader of diverse engineering teams, including those with multilevel, multi-disciplinary and multi-cultural dimensions.

(c) Earns the trust and confidence of colleagues through competent and timely completion of tasks.

(d) Recognises the value of alternative and diverse viewpoints, scholarly advice and the importance of professional networking.

(e) Confidently pursues and discerns expert assistance and professional advice.

(f) Takes initiative and fulfils the leadership role whilst respecting the agreed roles of others.

3.3.3 United States of America

In USA accreditation of all programs is the responsibility of ABET, the Accreditation Board for Engineering and Technology. ABET responded to calls from various groups that engineering education was overly focussed on technical knowledge and skills, to the detriment of personal capabilities during the 1990's. As a result of extensive workshops, recommendations were published entitled "A Vision for Change" [25] in 1995. These have produced changes in the desired direction for student outcomes of engineering degree programs that have been adopted by ABET. They have now specified the following student outcomes for accreditations in the 2011-2012 cycle of 4 year engineering Bachelor degree programs [26].

Programs must have documented student outcomes that prepare graduates to attain the program educational objectives. The student outcomes must include (a) through (k) in the outcomes that are articulated for each program.

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyse and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

These 11 student outcomes have a very close correlation to the Washington Accord graduate attributes.

3.3.4 OECD Learning Outcomes in Engineering

A valuable resource in this area is the OECD Report [12] which addresses the issue of learning outcomes in the context of the Bologna Agreement to move toward equivalence of professional qualifications in Europe. They have investigated the issues in some depth and stress that the learning outcomes can only be achieved if they are the focus of reliable and repeated assessment processes that should assist the student's learning as they proceed during their engineering program. This study has placed the learning outcomes in the categories of:

- Generic skills.
- Basic and Engineering Sciences.
- Engineering Analysis.
- Engine ering Design.
- Engineering Practice.

They are presented in considerable detail for those seeking more detailed specifications for program design and outcome assessment. The OECD have studied the learning outcomes specified for engineering program accreditation around the world, and have developed this agreed set, with the participation of representative practitioners in engineering education, which seeks to embrace all the identified national objectives. The agreement has also specified detailed learning outcomes for each of civil, electrical and mechanical engineering which go into a level of detail that is avoided in the Washington accord statement of graduate attributes. Since the graduate attributes need to be translated into measureable outcomes by each institution and for each program, this report may provide tangible assistance to course designers. The study makes a claim that progressive developments have occurred in engineering education over recent years and that it has become far more student-centred. However, this unsubstantiated claim contrasts with much of the evidence provided in the literature.

3.3.5 Asia

Asia is a major educator of engineers. The situation with accreditation of engineering education programs varies considerably from country to country in Asia as a result of its enormous diversity. The current situation is described in the Contributed Panel authored by Jia-Yush Yen and Mandy Liu.

3.3.6 Africa

Africa is a continent in a relatively early stage of development and the major engineering projects are usually undertaken by international companies that will employ some locally educated engineers. Consequently the engineering education programs at the local universities are at an early stage of development and, with the exception of South Africa, are restricted by an inadequate availability of resources. The Contributed Panel authored by Funso Falade describes the situation in detail. There is, however, an opportunity for advancement if Africa chooses to follow the transformed program model of engineering education described here, instead of the commonly used traditional model.

Contributed Panel No. 1:

Co-operating to Enhance Engineering Education in Asia

Jia-Yush Yen[1], Mandy Liu[2]

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Abstract

The paper reports on the current status of engineering education in some of the Asian countries/economies, with particular attention on accreditation of engineering education to achieve quality assurance. The Network of Accreditation Bodies for Engineering Education in Asia (NABEEA) has taken a leadership role to facilitate regional cooperation among the accreditation bodies as a way to help advancing engineering education in the region as well as in the world.

Introduction

As the world enters the twenty-first century, Asia as a whole has been growing in significance in many aspects of the world's affairs. A large proportion of the world's most highly trained human capital originates from Asia. While many of these top talents were once driven to the western world for better career opportunities, they are now motivated to return or stay in Asia because of their cultural roots. Most of the Asian economies have taken more active, if not aggressive, steps to engage in all aspects of development and thus attract and nurture professionals. This trend is evident in many professions and is prevalent in engineering. The progress can easily be observed from the seemingly explosive rise of accreditation systems of engineering education and engineering mobility agreements in the region.

Engineering serves as the backbone of a country's economy and development, and the quality of engineering education is therefore of crucial importance. We have seen a growing number of Asian economies adopting accreditation system for engineering education and moving to participate in worldwide agreements for recognition. The most popular of such agreements is the Washington Accord. It establishes that graduates of programs accredited by any of the signatory bodies will be recognized by the other signatories as having met the academic requirements for entry to the practice of engineering[1].

Although there is no regional agreement for the recognition of accreditation systems and engineering degrees in Asia, there have been several significant efforts developed to promote benchmarking and cooperation. The Network of Accreditation Bodies in Engineering Education Accreditation (NABEEA) was founded in 2007 as a loosely connected network by a group of Asian economies that are signatories to the Washington Accord. NABEEA has continued to grow as more accreditation bodies have come on board over the years. A key objective of the network is to support and inspire those members that are not Washington Accord signatories to be admitted to the Washington Accord.

Apart from the collaboration among accreditation bodies to promote the quality of engineering education, there are several engineering mobility agreements that aim to facilitate the mobility of engineers. The ASEAN Chartered Professional Engineer, APEC Engineer, and International Professional Engineers, are examples. Many Asian economies are represented in these forums with the objective of elevating the status and quality of their engineers.

Asian economies are at various levels as far as the quality of engineering education is concerned. However, they have demonstrated astonishing interest in participating in regional and international agreements. While the challenges are obvious and acute, regional collaboration in Asia will no doubt lead to great opportunities for the advancement of engineering education in the region.

Asian Economies and the Washington Accord

The Asian economies include some of the largest and most advanced technological infrastructures, and many of them have historically been proud of the high quality of their engineering education systems. In a mere fifteen years, six economies have become signatories of the Washington Accord, representing nearly half of the full members of NABEEA, and several others are provisional members.

As of 2011, the six Washington Accord signatories from Asia, are (in alphabetical order)[1]: Chinese Taipei – Represented by the "Institute of Engineering Education Taiwan (IEET)" since 2007, Hong Kong China – Represented by "The Hong Kong Institution of Engineers (HKIE)" since 1995, Japan – Represented by "Japan Accreditation Board for Engineering Education (JABEE)" since 2005, Korea – Represented by "Accreditation Board for Engineering Education of Korea (ABEEK)" since 2007, Malaysia – Represented by "Board of Engineers Malaysia (BEM)" since 2009, and Singapore – Represented by "Institution of Engineers Singapore (IES)" since 2006.

There are other economies that are in the process of applying for Washington Accord membership and some that are evaluating their situation. Among the bodies holding provisional status are: Bangladesh – Represented by "Board of Accreditation for Engineering and Technical Education", India – Represented by "National Board of Accreditation", Pakistan – Represented by "Pakistan Engineering Council", and Sri Lanka – Represented by "Institution of Engineers Sri Lanka".

The level of representation in the Washington Accord from Asian economies highlights the significance of Asia's engineering education in the world. Its development will influence not only the Asian economies, but also the world's engineering education as a whole.

Engineering Education Efforts in Asian Economies

The Asian economies place strong emphasis on the promotion of engineering education. All economies have implemented some form of quality assurance measure in their higher education systems. Many have also set up accreditation bodies to conduct accreditation of engineering education. The followings are observations of some selected economies:

1. **Bangladesh** is very actively promoting the quality of engineering education. There are thirty one public universities and around fifty one private universities. The government supports almost the entire budget of the public universities. The private universities, on the other hand, have to be self-sufficient. The University Grant Commission of Bangladesh, (UGC Bangladesh) controls and reviews the funding to the public universities. The Board of Accreditation for Engineering & Technical Education (BAETE) is the body for engineering accreditation. Current government regulation requires the private university programs to go through accreditation/evaluation. The public university programs are accredited on a voluntary basis. Bangladesh, represented by BAETE, is now a provisional signatory to the Washington Accord.

2. **India.** There are more than sixteen thousand universities in India. The large number of educational institutes makes the quality control of higher education the most important issue for the Ministry of Human Resource Development. There are not only rigorous regulations controlling the establishment of new universities, but also strict guidance on the course content of almost all of the engineering related subjects.

   The Institution of Engineers India (IEI) is the body in charge of professional licensing. IEI is a very large body with more than 600,000 members. Its operation is similar to most of the engineering institutes around the world with engineering licensing, memberships and trainings.

   The National Board of Accreditation (NBA) is the main body for engineering accreditation. NBA was originally a subsidiary of the All India Council for Technical Education (AICTE), but, to comply with the Washington Accord requirement, it is now an independent nongovernmental body. NBA stresses the need to meet international accreditation standards. One key issue that NBA is dealing with is the size of the geographical area. There are many remote learning programs that require careful review for accreditation. NBA has employed experienced foreign consultants to assist in the quality assurance for this special need. The NBA accreditation system is largely input based, but it is gradually moving toward becoming outcomes based. NBA is a member of NABEEA and is a provisional signatory of the Washington Accord.

3. **Indonesia.** The National Accreditation Agency for Higher Education (Badan Akreditasi Nasional Perguruan Tinggi, BAN-PT) is the body executing accreditation for the higher education programs or institutions in Indonesia. BAN-PT is government funded, but functions as an independent body. The BAN-PT evaluation includes all the programs in higher edu-

cation level. There are more than fifteen thousand higher education programs, and one third are engineering programs. BAN-PT adopts a great deal of the procedures used by the Washington Accord signatories.

4. **Mauritius.** The professional engineering licensing in Mauritius is governed by the Council of Registered Professional Engineers (CRPE). CRPE is a non-governmental body consisting of six members, with two representatives from each of the Institution of Engineers Mauritius (IEM), the government (with an engineering background), and industry. There is an independent Tertiary Education Commission (TEC) for administering the reviews of higher education institutions and the quality of engineering education is carefully monitored. There are only two universities in Mauritius with engineering programs, but TEC places strong emphasis upon quality assurance and has subjected the universities to 5 year cycle evaluations.

5. **Myanmar.** Myanmar Engineers Society (MES) is a nongovernmental body first established in 1916 and, after a brief disruption, re-established in 1995. MES is an ASEAN Federation of Engineering Organizations (AFEO) member. The professional engineering licensing in Myanmar, however, is governed by a governmental committee. Myanmar currently does not have an engineering accreditation body. Also, not all engineering institutions are under the jurisdiction of the Ministry of Education in Myanmar. Although MES is currently not practicing engineering accreditation, it is fully aware of the operation of Washington Accord and is evaluating the need to establish an engineering accreditation system compatible to the signatories of the Washington Accord.

6. **Philippines.** There are three accreditation bodies recognized by the Philippine government: the Philippine Accrediting Association of Schools, Colleges and Universities (PAASCU), the Philippine Association of Colleges and Universities Commission on Accreditation (PACUCOA), and the Accrediting Agency of Chartered Colleges and Universities of the Philippines (AACCUP). Members of PAASCU and PACUCOA are private universities, while AACCUP has members from public universities. These three accreditation bodies have agreed to joint efforts under the umbrella of the Philippine Technological Council (PTC) for the application of Washington Accord membership. PTC is a member of AFEO, FEIAP and WFEO. The Commission on Higher Education (CHED) of the Philippine government had also agreed to fund the accreditation and Washington Accord application. As a result, PTC is very active in promoting the quality assurance of engineering education in the Philippines.

7. **Thailand.** It has a large number of universities and the Thai government devotes extraordinary attention to the quality assurance of their higher education. The Quality Commission on Higher Education published a set of Education Quality Assurance Indicators in 2003 based on the National Education Act. The concept behind Thai quality assurance policy for higher education consists of two aspects: the internal quality assurance (IQA) and the external quality assurance (EQA). The IQA, as its name indicates, is a review internal to the university. The EQA, on the other hand, is conducted by the Office for National Education Standards and Quality Assessment (QNESQA). The ONESQA is currently conducting the second round of its EQA process for Thai higher education bodies. Concerning engineering education, there is the Council of Engineers (COE) responsible for engineering accreditation. COE has established its rules and regulations in accordance with Washington Accord (WA). COE is a member of NABEEA and is in the process of applying for WA membership.

8. **Vietnam.** The review of higher education institutes commenced in 2007. For engineering, the body currently responsible is the Vietnam Union of Science and Technology Associations (VUSTA). VUSTA is a member of many international bodies including: the World Federation of Scientific Workers Organizations (WFSWO), the WFEO, the FEIAP, and the AFEO. The Vietnamese licensed engineers are recognized by the ASEAN Chartered Professional Engineers. VUSTA has around half a million members including scientists and technologists, and is very aware of the importance of the quality and competence of its professional engineers. Because engineering education lays the foundation of engineering training, VUSTA has been observing the recent development in engineering accreditation. Draft rules and regulations been prepared. VUSTA is also planning to establish an "Institute of Engineers" as the governing body for engineering licensing and engineering accreditation.

Network of Accreditation Bodies for Engineering Education in Asia

NABEEA is a network of accreditation bodies in Asia. The network was first proposed by JABEE and resulted in the first network General Assembly meeting held on August 8, 2007 in Penang, Malaysia. The goal of the network is to promote engineering education and develop mutual cooperation towards better accreditation systems in Asia by exchanging information on engineering education and accreditation systems and by identifying the similarities and dissimilarities of the economies so as to achieve harmonization of the accreditation systems[2].

NABEEA has initially initiated three projects: 1.The Rules and Procedures of NABEEA (led by ABEEK); 2. The Glossary of Terminologies for Accreditation of Engineering Education (lead by IEET) for common understanding of terms used in accreditation of engineering education; and 3.The Report on Issues in Engineering Education Accreditation in Asian Jurisdictions (led by IES) to highlight the characteristics of the members' engineering education and accreditation systems. The results from these studies will be published on the NABEEA website.

There are two types of membership in NABEEA: full member and associate member. Full members are the accreditation bodies whereas associate members are normally the professional engineer institutes. The five founding members: ABEEK (Korea), EAC of BEM (Malaysia), IEET (Chinese Taipei), IES (Singapore), and JABEE (Japan) are also council members. The other full members are BAETE (Bangladesh), COE (Thailand), NBA (India), PEC (Pakistan), and PTC (the Philippines). BPERB (Bangladesh), CIE (Chinese Taipei), IEM (Malaysia), IPEJ (Japan) and KPEA (Korea) are associate members.

As NABEEA moves forward, there are three major areas to which the members will pay particular attention. The first is to encourage more neighbouring economies to become members, the second is to advance mentoring efforts to help those members that are not yet Washington Accord signatories to comply, and the third is to deepen the practice of the outcomes-based accreditation system by promoting the Graduate Attributes of the Washington Accord among members.

Conclusions

Asia consists of many ancient countries/economies, and its diversity is also reflected in the engineering education systems. It has witnessed many promising developments in recent years as the Asian economies elevate the quality of education most significantly through participation in the regional and international mutual recognition agreements. Economies that are involved in this movement are experiencing great change in the way engineering education is viewed and developed. These actions will lead to the betterment of engineering education in the region and beyond.

Acknowledgement

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Contributed Panel No. 2:

Effects of Challenges in Engineering Education on African Development

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Engineering is the application of scientific methods to technology and technology is the driving force for national/regional development. Engineers are required to solve societal problems in sustainable ways. For them to do so, they need to be sufficiently informed in engineering concepts and the application of engineering theoretical principles to solving practical problems. In Africa, the desire of the stakeholders to achieve this outcome has been confronted by many challenges. Our inability to tackle the challenges appropriately in Africa has contributed to our low level in technology and hence development.

Universities and polytechnics are repositories of knowledge. Experts in various engineering disciplines are available in these institutions whose primary duty is to extend the frontiers of knowledge. However, the ability to impart knowledge effectively and contribute to national development is severely limited by the following challenges.

Funding

The major challenge in knowledge acquisition and capacity building in engineering education is paucity of funds. UNESCO recommends the allocation 26% of annual national budget to education, but most countries in Africa do not approach this figure in their annual allocation to education. Under-funding manifests in poorly equipped laboratories, inadequate library stock, poor salaries with low staff morale and brain drain (African Human Development, 2006). The inadequacy of

Table 1: Percentage of Staff with PhD to those without PhD.

	UON	Addis	UZ	JKUAT	Bots	Malawi	ABU	Unilag*
Subject								
Civil	28.00	18.75		27.27	56.25		36.36	70.59
Mechanical	52.17	20.00		30.43			20.00	27.27
Met & Mat								46.15
Systems								71.43
Electrical	46.67					77.78	41.67	43.48
Electronic		60.00	50.00			5.88		
Chem/Biochem		38.10				12.50	30.77	57.14
Comp Eng		60.00						
Mining			60.00					
Industrial		42.86	75.00		50.00			
Production				85.00	14.29			
Agricultural	44.44						40.00	
Survey	35.71						50.00	30.00

Source: Massaquio (2004), * Falade (2008) teaching and research facilities has contributed to the diminution of the quality of engineering graduates.

Human Resources

Many universities across the African region are inadequately staffed both qualitatively and quantitatively. For example, in Nigeria, the National Universities Commission (NUC) Minimum Academic Standards stipulate a staff: student ratio of 1:15 but in general, the ratio hovers between 1:24 and 1:35. In extreme cases it can be as high as 1:90. Statistics shows that less than 10,000 academic staff are available to do the work of the 36,000 academics required by the university system. Table 1 shows the ratio of academic staff with PhD to those without PhD expressed as percentages in some engineering disciplines in some African universities. The table indicates that there is a higher proportion of non-PhD holders. The low level of expertise indicates that capacity building is required in various engineering disciplines. Njunwa (2008) noted that the goal of human resource development is to promote industrialization in a country in order to achieve economic growth and development. He further noted that brain drain has contributed to inadequate capacity building efforts in Africa.

Poor Infrastructure

The number of science, engineering and technology training institutions in Africa is rather few. In most of the existing Universities and many of the Research Institutes, basic infrastructure (energy and water) is in a poor state especially in the laboratories for the basic sciences as well as within the laboratories and workshop for engineering and technology. Apart from the fact that the salaries of staff in teaching and research institutions are extremely low in Africa, as compared with other regions of the world, the working environment of these same researchers in terms of access to financial resources, tools and other equipment and research facilities like computers, is very poor. At the root of national development is the utilization of research and innovation. A society that fails to invest in research and innovation will have stunted growth and this is precisely the situation in African nations except South Africa.

Weak University-Industry Partnership

Generally, the industry leaders are not involved in defining the research agenda, nor do they participate in the development of engineering curricula to allow them to integrate into the curricula, the areas of needs of industry. Consequently the two sectors operate at different levels with different agendas. Also the multinationals usually locate their research units in their home countries. This constitutes a major setback to properly aligning industry needs with what the students are taught in the classroom (Falade and Ibidapo-Obe, 2005). To pave way for development, the partnership between universities and industry must be strengthened, with Universities providing the platform for the creation of knowledge and the development of human resources and with industry providing the platform for commercialization of the research outputs. Otherwise development will continue to elude African nations.

Political Will

African nations have been, and to a large extent continue to be, ruled by persons who are not too committed to development and not too enthusiastic about addressing those factors that could lead to its realization. Generally, over time, education, including engineering education, has been neglected. Engineering educators have the considerable challenge of convincing the law makers of why they (law makers) should give priority to engineering in allocating resources. Options of how to achieve positive results have been advocated in different forums, and include lobbying, participation of engineers in government, wooing, etc. For the necessary development to take place, government must provide an enabling environment for both university and industry to operate and also fund engineering research projects (Falade, 2010).

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3.3.7 Europe

The European Network for the Accreditation of Engineering Education (ENAEE) has co-ordinated the definition of the European Accredited Engineer (EUR-ACE). The Bologna Process which adopted the 3+2 model for European engineering degrees stimulated debate about what knowledge an engineer should possess. The accreditation agency has conducted a process which has led to the definition, in general terms, of the capabilities required of graduates from accredited First Cycle (Bachelor) and Second Cycle (Master) engineering programs as an entry to the profession. These are [27]:

Programme Outcomes for Accreditation

The six Programme Outcomes of accredited engineering degree programmes are:

1. Knowledge and Understanding,
2. Engineering Analysis,
3. Engineering Design,
4. Investigations,
5. Engineering Practice,
6. Transferable Skills.

EUR-ACE Framework Standards for the Accreditation of Engineering Programmes

1. Knowledge and understanding

The underpinning knowledge of science, mathematics and engineering fundamentals are essential to satisfying the other program outcomes.

Graduates should demonstrate their knowledge and understanding of their engineering specialisation, and about the wider context of engineering.

First Cycle graduates should have:

- knowledge and understanding of the scientific and mathematical principles underlying their branch of engineering;
- a systematic understanding of the key aspects and concepts of their branch of engineering;
- coherent knowledge of their branch of engineering including some at the forefront of the branch;
- an awareness of the wider multidisciplinary context of engineering.

Second Cycle graduates should have:

- an in-depth knowledge and understanding of the principles of their branch of engineering;
- critical awareness of the forefront of their branch.

2. Engineering Analysis

Graduates should be able to solve engineering problems consistent with their level of knowledge and understanding, and which may involve considerations from outside their field of specialisation. Analysis can include the identification of the problem, clarification of the specification, consideration of possible methods of solution, selection of the most appropriate method, and correct implementation.

Graduates should be able to use a variety of methods, including mathematical analysis, computational modelling, or practical experiments, and should be able to recognise the importance of societal, health and safety, environmental and commercial constraints.

First Cycle graduates should have:

- the ability to apply their knowledge and understanding to identify, formulate and solve engineering problems using established methods;
- the ability to apply their knowledge and understanding to analyse engineering products, processes and methods;
- the ability to select and apply relevant analytic and modelling methods.

Second Cycle graduates should have:

- the ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications;
- the ability to formulate and solve problems in new and emerging areas of their specialisation;
- the ability to use their knowledge and understanding to conceptualise engineering models, systems and processes;
- the ability to apply innovative methods in problem solving.

3. Engineering Design

Graduates should be able to realise engineering designs consistent with their level of knowledge and understanding, working in cooperation with engineers and non-engineers. The designs may be of devices, processes, methods or artefacts, and the specifications could be wider than technical, including an awareness of societal, health and safety, environmental and commercial considerations.

First Cycle graduates should have:

- the ability to apply their knowledge and understanding to develop and realise designs to meet defined and specified requirements;
- an understanding of design methodologies, and an ability to use them.

Second Cycle graduates should have:

- an ability to use their knowledge and understanding to design solutions to unfamiliar problems, possibly involving other disciplines;
- an ability to use creativity to develop new and original ideas and methods;
- an ability to use their engineering judgement to work with complexity, technical uncertainty and incomplete information.

4. Investigations

Graduates should be able to use appropriate methods to pursue research or other detailed investigations of technical issues consistent with their level of knowledge and understanding. Investigations may involve literature searches, the design and execution of experiments, the interpretation of data, and computer simulation. They may require that data bases, codes of practice and safety regulations are consulted.

First Cycle graduates should have:

- the ability to conduct searches of literature, and to use data bases and other sources of information;
- the ability to design and conduct appropriate experiments, interpret the data and draw conclusions;
- workshop and laboratory skills.

Second Cycle graduates should have:

- the ability to identify, locate and obtain required data;
- the ability to design and conduct analytic, modelling and experimental investigations;
- the ability to critically evaluate data and draw conclusions;
- the ability to investigate the application of new and emerging technologies in their branch of engineering.

5. Engineering Practice

Graduates should be able to apply their knowledge and understanding to developing practical skills for solving problems, conducting investigations, and designing engineering devices and processes. These skills may include the knowledge, use and limitations of materials, computer modelling, engineering processes, equipment, workshop practice, and technical literature and information sources. They should also recognise the wider, non-technical implications of engineering practice, ethical, environmental, commercial and industrial.

First Cycle graduates should have:

- the ability to select and use appropriate equipment, tools and methods;
- the ability to combine theory and practice to solve engineering problems;
- an understanding of applicable techniques and methods, and of their limitations;
- an awareness of the non-technical implications of engineering practice.

Second Cycle graduates should have:

- the ability to integrate knowledge from different branches, and handle complexity;
- a comprehensive understanding of applicable techniques and methods, and of their limitations;
- a knowledge of the non-technical implications of engineering practice.

6. Transferable Skills

The skills necessary for the practice of engineering, and which are applicable more widely, should be developed within the programme.

First Cycle graduates should be able to:

- function effectively as an individual and as a member of a team;
- use diverse methods to communicate effectively with the engineering community and with society at large;
- demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice;
- demonstrate an awareness of project management and business practices, such as risk and change management, and understand their limitations;
- recognise the need for, and have the ability to engage in independent, life-long learning.

Second Cycle graduates should be able to:

- fulfil all the Transferable Skill requirements of a First Cycle graduate at the more demanding level of Second Cycle;

- function effectively as leader of a team that may be composed of different disciplines and levels;
- work and communicate effectively in national and international contexts.

While these have some parallels with the Washington Accord Graduate Attributes, a direct comparison is made difficult by the two stage qualification system. Although the non-technical attributes are included, they appear to be given somewhat less emphasis than is given in the Washington Accord.

3.3.8 South America

The education of engineers in South America has also followed a diverse pattern as a consequence of the various influences arising during the colonization period. The situation is described in detail in the Contributed Panel authored by Claudio da Rocha Brito.

Contributed Panel No. 3:

Engineering Education in South America: Perspectives for the 21st Century

Claudio da Rocha Brito

President of COPEC – Science and Education Research Council, Brazil.

Introduction

The goal of this contribution is to describe some aspects of engineering education in South America: the origins, cooperation and education policies, the differences and difficulties of engineering program integration and perspectives for the future.

Although for the most part, the countries in South America are in development, it constitutes a huge and complex economic market. The characteristics of globalization have brought to the governments and to educational institutions a huge challenge: to develop professionals for the new millennium. Professionals committed with the goal of providing science and technology to promote the development of their countries.

In a global world where borders between countries are being removed to facilitate the action of big corporations, the formation of economic blocks to protect the interests of the companies established in the regions became necessary. Mercosur, the Southern Common Market, is not only an economic block, but also the result of European expansion (in fifteenth, sixteenth centuries) of world capitalism into Latin America.

Historically the colonization of South American countries was very different from the rest of the world and so was the development of science, technology and education. However in attempting to promote a common educational system, in 2000, Argentina, Brazil, Paraguay and Uruguay, the founding members of Mercosur, agreed to recognize each other's university degrees in medicine, agronomy and engineering. The objective is to have universities adhere to common standards so that professionals from one country can work in the others.

The perspectives for the future of the region are uncertain, as, although it is a portion of the planet with really generous natural resources, the countries are still fighting against poverty and the mentality of the majority of their politicians, whose education policy is education for the elite. It is not an easy task to change this mentality because culturally the politicians govern for a privileged minority and are always complying with the interests of the economically stronger countries.

Pressured by the necessity to promote scientific and technological development, taking into account the environmental issues (costs and benefits), a new mentality became necessary in government. That has been a positive outcome of globalization. On the other hand, it is a process that takes time to accomplish. So, in this scenario, education emerges as the key factor that can guarantee the people the possibility of achieving sustainable development.

The importance of engineering for these countries is crucial because engineers are the professionals that create the ideas and transform them into goods and services. So it is of fundamental importance that there is good formation of what is called “Engineers of Conception” who can lead the scientific and technological development of a country.

The main aspect of this analysis is the relevant importance of engineering for the development and progress of a country, in a context of global society where new and very high technologies dominate the world, and when more than ever, it becomes necessary to achieve the formation of well qualified professionals. It is important to mention the efforts of universities and schools to accomplish their mission to form a new engineer prepared to face the new world work market.

Equally important, is the discussion about engineering education occurring in different geographical parts of the time to explore the views world. It is a way to promote and increase awareness of contemporary engineering education efforts and at the same of young people, teachers, engineering lecturers and policy makers from other parts of the world[1].

Higher Education in South America

It is hard to find updated information about engineering education in countries of South America. Little numerical data is available on Peru for example. University professors symbolize a high order of achievement, and they are addressed as professor or professora.

The same recognition of educational achievement is given in other fields as well. Anyone receiving an advanced degree in engineering is always addressed as engineer (ingeniero) or doctor. The titles are prestigious and valued and permanently identify one as an educated person to be rewarded with respect. The titles are therefore coveted, and on graduation the new status is often announced in El Comercio, Lima's oldest daily newspaper[2].

Chile has a higher education system of 25 public universities and over 50 private universities. There are also technical and professional training institutes which focus on programs leading to specific vocational careers rather than academic degrees. Admission to the public universities and some of the older private universities is based on scores on the University Selection Test, known as the PSU, and secondary school grades. The PSU is made up of several subtests and is similar to the SATs that are used by US schools. Each university sets its own admission criteria with the more highly regarded public universities having more selective criteria than newer private universities.

Accreditation of universities is the responsibility of the National Accreditation Commission which provides evaluations in five different areas. Fewer than 20 universities have received accreditation in all five areas and many smaller, private universities have no accreditation.

Public universities receive about one-third of their funding from government sources with the remainder primarily coming from student fees. Tuition fees are substantial, but there are a number of student grants and loan programs to help financially needy students. Tuition fees at private universities are not substantially higher than at public universities[3].

For other countries the information about engineering education is very limited and updated statistics are not available. So the majority of the information is about Brazil and Argentina engineering programs, the major countries of the continent. The developments in the educational systems of these two countries will enlighten the development of education in this part of the globe. It will bring updated information and convey the framework adopted to defeat the present obstacles and demands, in order to face the current educational crisis.

Discussions about Education in Brazil

Brazil Superior Education has a history of success, but has been encountering some problems of a social and financial nature. It commenced with the creation of

Public Universities in the many states of the country, which have worked very well for many years; the Country has built a solid reputation creating generations of Brazilian scientists and educators. However, there is still a long road to travel by the three major agents: the State, that has to generate and apply public policies in science and technology, besides financing them; the University, which develops qualified personnel and creates basic science; and Industry, that should invest in technology creation, accomplish applied research, incorporate qualified personnel and be competitive[4].

The scientists, fortunately, have refused to accept the ominous and narrow-minded neo-liberal policies confronting education, have started fighting to maintain current achievements and support actions to maintain and to enhance the researchers in every field of science and technology. Valuable discussions at a national level during conferences, using all communication media, have taken place for many years and continue with the aim of influencing political opinion. It seems to be a lonely fight when global economic issues are such a powerful influence[5].

Despite all the problems, professionals and educators of every field of science and technology have been discussing the destiny of education in the country, taking into account the historical context of the world. Certainly some of these discussions have generated practical actions at governmental level as a response to those sections of society that are most interested in the issue. In Brazil the situation in engineering and technological fields is very delicate. Although the proliferation of private universities all over the country has expanded the number of 3rd grade students it does not assure the increase of students in engineering and technology areas.

In order to understand the present situation of teaching in Brazil, it is important to note that public policy in education has the objective of democratizing teaching. These policies are contained in the Sampaio Doria Reform of 1920 and the Expansion of Junior High School implemented in1968-70; both educational reforms attempt to promote education for all[6].

Engineering History in Brazil

Engineering history in Brazil started with military engineering, which at that time was basically the construction of fortifications to provide solutions for defence. It evolved into civil engineering. The colonization of Brazil, plus the insurance aspect of Portugal, made the royal government recognize the necessity of forming the national engineer. It was achieved initially by using the evolving French Schools of Engineering.

Portuguese style of construction can be seen everywhere in Brazil and the engineering schools still maintain the European style because of the strong influence of these countries during the colonization process. The evolution of engineering in Brazil follows global trends very closely. From the construction of fortifications through electrical engineering to mechatronic engineering, it has developed in accordance with the need to promote the development of the country by the best applications of science and technology using local resources.

Many accomplishments of big proportions can be seen, not only public buildings and houses, but also practical applications of electricity like telegraphy, telephony and lighting. The utilization of electrical energy in Brazil happened at the same time as industrial expansion occurred in developed countries. Since the Fortification Classes and Military Architecture founded in Bahia in 1699, more than 200 engineering schools have been created and engineering education has had a history of success, full of many conquests and accomplishments[7].

The Role of Engineering in Science and Technology

Brazil is five hundred years old with a history of races interacting to construct a social identity with diversity and cultural richness. The challenge of starting this new millennium is to build a new Brazil; a Country where the quality of life on a daily basis is enjoyed by its 166,113,000 inhabitants and not only by a minority.

Considering the history of humanity, the importance of engineering and engineers in developing and shaping a new social world order, creating a new life style and a new way of thinking, is quite evident.

Recognizing the importance of engineering, Brazil has been working to improve the competitiveness of its national goods and services by means of an incentive to create projects to increase the number of professionals through continuing education. For example[8]:

- It implicitly links itself to a single model of higher education (following the same rationale and being directed by the same values);

- It has been designed without considering the reality of the job market (top-down policy);
- It seems to have taken its inspiration from the North American model, which could provide a certain guarantee, but it appears to be following a very different path.

For these reasons, pragmatically, they should remain open to the application of the Bologna principle or other solutions, such as having:

- a limited number of universities in a position to be competitive at the world level;
- some universities with credible expertise and know-how in some fields– the so-called technological clusters;
- a high level of flexibility and response, to launch new types of programs.

In most European countries a distinction has been made throughout history between a scientifically oriented syllabus and a more practically oriented syllabus. Strict following of the Bologna guidelines could lead to a complete re-formulation of the educational system on a new basis. The examples of Sweden, the Netherlands and to a certain extent Germany show a more pragmatic approach, with a willingness to reconcile the Bologna principles with a lengthy tradition.

Mobility of students to and from other countries is considered an important goal according to Bologna. In the case of Portugal, some difficulties occur related to the language now used in the engineering courses (Portuguese). Teaching the Master courses in English, as in Norway, could be a positive opportunity[9].

The Bologna process has opened many opportunities for students in South America with the Erasmus program, promoting mobility of students of both regions, which enriches the formation of engineers and enhances the cross cultural skills so important for the global work market.

Higher Education of Engineering in Argentina

Throughout Argentina's history, the teaching of science and distinctive engineering-related technology has been through many changes and the tension between theoretical and practical training has always been present.

In nineteenth century, in the revolutionary period that led to independence, the practice of engineering was linked with Spanish military engineering. In 1821 the University of Buenos Aires was created and the first mathematical studies related to engineering education and the creation of Civil Engineering occurred in 1870.

In the last decade of the twentieth century, many universities were institutionalized in the Greater Buenos Aires. Engineering programs were created taking into account the technical characteristics of the social and humanistic training of engineers. Also higher education in Argentina incorporated a number of important private universities.

Currently engineering training is by University Education and its qualifications are regulated by the state and their actions are in the public sphere[10]. Only 1 in 5 students are female.

Engineering degrees offered in the country are as follows: Aeronautical Engineering; Environmental Engineering; Food Engineering; Surveying Engineering; Biomedical Engineering and Bioengineering; Civil Engineering; Electrical Engineering; Electromechanical Engineering; Electronic Engineering; Hydraulic Engineering; Industrial Engineering; Materials Engineering; Mechanical Engineering; Metallurgical Engineering; Mining Engineering; Nuclear Engineering; Petroleum Engineering; Chemical Engineering; Telecommunications Engineering; Systems Engineering; Naval Engineering; Engineering Geodesy and Geophysics; Agricultural Engineering; Forester[11].

Mercosur

For good or for bad the Mercosur is a reality that is still working despite the deep differences between the four countries. For the future more integration can be foreseen in many activities and a similar education system is one of them. Discussions have started to find a way to achieve this goal and as a first concrete step in Brazil, for example, High School students learn Portuguese and Spanish plus the option of another foreign language[12].

Superior Education in South America and the Efforts of the Iberian Peninsula

Education in South America has been strongly influenced from Europe, naturally, because European peoples colonized all the countries. Despite the huge influence from USA, by means of communication, principally cinema and TV, these countries still have a European style of education. They still have a Napoleonic university with variations of the German style of education.

In Brazil like in many other countries of South America there are three different conceptions of university: the one that was born in medieval era with tutors and advisers, masters and students; secondly the university for science in the service of social good and beauty; and finally the functional university that contributes to social and economic development.

The engineering schools follow the Swiss model of ETH of Zurich with some exceptions that follow the French model and also some that form what is called “Engineer of Appliance”.

Lately many transformations have occurred with the goal of equalizing opportunities and supplying the demand of local markets. It is clear that while Mercosur was conceived predicting similar education systems for the countries of the *South Cone,* it will take a long time for this objective to be realized because of the differences among the educational systems and the different social realities.

The countries of Iberia Peninsula have promoted a remarkable effort toward a new approach to engineering education. The goal is to enhance cooperation programs and the development of collaborative projects between their universities and Latin America’s universities through the ASIBEI – Iberian-American Association of Engineering Education Institutions. This process started in 1997 by the Spanish and Brazilian engineering schools followed by the other universities of Latin America. Annual meetings are kept for the discussion of new policies to achieve an integration of engineering programs. In the last meeting that took place in the Military Institute of Engineering, in Rio de Janeiro in 2001 the discussions leaded to the “Rio de Janeiro Declaration”. It contained some guidelines for future conversations about collaborative programs. The guidelines propose three main characteristics of the Engineer of *Iberia America*:

1. Strong knowledge about basic science;
2. Generalist formation;
3. With social concerns

Despite the efforts of all the participants, there were some impediments for the accomplishment of a real Engineer of Iberia America: the arrogance of Spanish academic community; their insistence to sell obsolete programs; a huge necessity to create a work market for Spanish Engineers; the North American influence; the Latin American reality; the absence of Portugal in the process; and the internationalization of education with the *Bologna Declaration* and its incidence in Latin America and the French-Brazilian Diplomas.

Despite the difficulties, it is important to point out that many engineering schools have been conceived and implemented new engineering programs with the goal to form the new engineer to face the demands of twenty first century[13-14].

Final Remarks

In South America engineering education has been transformed like in Europe and USA. It has been facing the same challenges to transform the engineering education system to meet the demands of a new social and economic order, and has started a move to search for the best technologies. Additionally there is the reality of developing countries being submitted to international policies imposed by the developed countries.

In this scenario the efforts of educators with a vision of the future emerge, promoting the betterment of engineering education and fostering the cooperation among the Schools of the four countries of Mercosur.

It is possible to notice that even with the colonization process in Iberian America’s countries, due to the several other sources of influence as a consequence of the immigration waves, the fight for excellence is an on-going process.

Although the Mercosur is a reality, there are still many difficulties to overcome. The different cultural, social and economic reality of each country impacts upon the accomplishment and acceptance of the educational project. Despite all the difficulties generated by international policies and the global economy, the efforts of the countries involved have been strong enough to keep working toward making its vision a reality.

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3.4 Employer's Views on the Attributes Required of Engineers

The employer's are key stake-holders of the engineering education process and their opinions about the performance of graduates must be extremely relevant to, and important for, universities and academics. Obviously their perspectives will vary considerably as they will include: small and large employers, local and international companies, private and government enterprises, companies with varying technology interests, manufacturers, miners, high technology enterprises, infrastructure contractors and others.

They may also have quite differing relationships with universities. Some will have close relationships through research and development projects, graduate recruitment, student projects and student internships, membership of university advisory committees or joint staff appointments, while for others there will be no significant ongoing relationship.

Employers have been active participants in the professional bodies that have developed the specifications of the desired attributes of engineering graduates that have been discussed in Sections 3.1 & 3.3. Their views have focussed upon the need to educate engineers more broadly with a view to developing their capability and capacity to undertake the role of the engineer as outlined in Section 2.2. They have recognised that the technical knowledge gained by students can only be a platform for the development of further knowledge during their career as it cannot be predicted what field of technical activity will become their focus, the technologies are subject to rapid change, and it may be essential to have multi-disciplinary knowledge.

Engineers rapidly become involved in complex projects and become team members and leaders with responsibilities that are quite diverse as both design and implementation involve many different considerations and skills. This may involve them in multi-national interaction, considerations and assignments. Preferred graduates have more than professional engineering skills; they possess maturity, demonstrate leadership capabilities, be good communicators and accept responsibility. A key ability sought in engineers is the ability to analyse: problems, situations, ramifications, consequences, short-term and long-term effects, financial impact, environmental impact, etc., with a view to advising or taking the appropriate actions. Engineers must be good at asking questions such as: Why is that so? Are you sure? What fact is that based on? [28]

With these capabilities, engineers have a much broader range of career options than just technological design and project management. As technology impacts an increasingly broad range of activities in our societies, engineers have significant roles to play in developing strategies, project options, relating to stakeholders, specifying creative outcomes and solutions, planning implementation, costing and managing. This is true for both government and commercial projects. Engineers have been increasingly utilised in recent years in financial strategy evaluation, but there is a need for their attributes to play a bigger role in business management, government departments and parliaments.

There remains serious concern by industry that the strategy to change the emphasis of engineering education has not yet been successfully implemented by universities that are still overly focussed upon the technical content components in their programs. A typical quotation is "Our engineering schools are turning out great scientists but mediocre engineers." [29]

A study of industry views relating to the quality of engineering graduates in the UK [30] gives fairly diverse views that differ between small and large employers. Generally more breadth and depth of soft skills are desired, but not at the expense of technical expertise. They also believe that both groups of skills should be more practical. They are seeking to recruit engineering graduates who combine technical expertise with practical ability, backed up by strong interpersonal skills, including an awareness of commercial realities. They indicate that the role of engineering graduates could be in any of the three following domains:

- The engineer as specialist, recognising the continued need for engineers who are technical experts of world-class standing.
- The engineer as integrator, reflecting the need for engineers who can operate and manage across boundaries, be they technical or organisational, within a complex business environment.
- The engineer as change agent, highlighting the critical role engineers must play in providing the creativity, innovation and leadership which is essential to shape the industry in an uncertain future.

Engineers in each domain are critically dependent upon the defining and enabling skills by which engineers are characterised. Engineers normally operate in one of these domains, although they may shift domains during their career or operate occasionally in two domains at the same time.

A survey recently conducted in Australia [13] asked 89 experienced people responsible for employing engineers to rate the relative importance of 65 attributes that could be reasonably possessed by an exemplary engineering job applicant with 10 years of experience. The survey used a cross-comparison method to establish a definitive ranking. The most highly valued attributes were:

- Integrity, ethics, transparency
- Accountable
- Safety awareness
- Communication
- Self-management in Engineering Workplace
- Teamwork and collaboration
- Service Excellence
- Client focus

Interestingly specific technical skills and knowledge were not the most important attributes in the employment decision in these circumstances. However it is clear that the hypothetical applicants could be safely assumed (on the basis of past experiences) to possess an appropriate technical capability and that the personal attributes are more likely to be the critical factors in determining the candidate's performance in their role.

3.5 Achieving Outcomes Based Education

It is widely acknowledged that engineering education requires a transformation to produce graduates, in sufficient numbers and with appropriate knowledge and skills, to provide the capabilities to address the many technological issues and projects that are required for the development of our communities. While the calls for transformation have not yet been considered (see Section 4.3), the specification of the attributes that are considered to be essential has been examined. There is considerable agreement between professional organisations, employers and educational institutions that these are appropriate. They have been deliberately broadened over the last twenty years, from a focus on technological skills and knowledge, to include the personal skills and capabilities that are considered to be essential for engineers in the 21st century.

Are the specified graduate attributes appropriate? They seem quite appropriate in this current period of technological change as they are not prescriptive or restrictive in assuming that any particular breadth versus depth profile is to be preferred in all cases. They have been developed with broad participation and detailed consideration and have been adopted by the professional engineering bodies of many countries. Some employers have raised two additional issues:

- Firstly, that work experience should be included in the student's program. While this may be very formative and valuable for students it is not likely to become prescriptive as it is difficult to guarantee its availability. It has been proven to be most beneficial and should be utilised if at all possible.

- Secondly, that since engineering increasingly involves international projects, with multi-national organisations co-ordinating design and implementation teams, there is a need for multi-cultural skills and that international experiences would also be advantageous.

There is much merit in these suggestions and an additional attribute relating to work experience or international experience could be justified. Approaches to addressing these issues will be discussed in Sections 5.9 and 6.8 respectively. It is obviously possible for individual universities to conceive appropriate ways for their students to experience activities that enhance these suggested desirable attributes without them becoming mandatory.

The key question remains: Are the graduate attributes, which are specified as the international benchmark for engineering education, being appropriately developed by universities? It is clear that the majority of engineering programs remain heavily weighted towards the knowledge components of the desired attributes [31]. This is evident from examining course structures and from the feedback of employers. The change that is essential is for engineering education to become an outcome focussed education process, where the desired outcome is the realisation of the complete spectrum of specified graduate attributes by each graduate in all educational institutions. Each attribute requires specific learning experiences for its development. Engineering programs must be designed to explicitly provide a range of learning experiences that enable all the essential graduate attributes to be realised by each graduate. It is also essential that the achievement of each required attribute is assessed by the education provider, and that the processes utilised and the standards achieved are verified and assured by the certifying authority.

Outcomes based education is a logical and necessary strategy since the outcomes specified must be achieved to receive the formal recognition of the graduates as Graduate Engineers by their professional registration organisations. It is clearly good educational practice to focus on the outcomes that must be achieved by the graduates in the design and delivery phases of the program. Why is it not the norm? What are the issues preventing this from occurring? How may it be implemented for the education of all engineers? These questions must be asked and answered by both the accreditation authorities and the universities. It will require the commitment of, and action by, the profession's accrediting authorities, the universities, their staff and the engineering employers [32]. It is a key component of the pathway to transformation.

While the graduate attributes have a commendable coverage, are understandable and suitably brief, they are not standards. These must be developed for each component of each attribute for each university program. For example:

- What standard of communication skills are to be developed and demonstrated in oral and written presentations by each graduating student? What suitable evidence needs to be provided?
- What tools and which complex engineering problems will be utilised to demonstrate the analysis and modelling capabilities of each student?
- How will leadership and teamwork skills be developed? What level of performance is to be achieved and demonstrated?

A full list of the standards required to demonstrate the achievement of each of the elements of the graduate attributes, is an essential requirement for the design, delivery and accreditation of each engineering education program as it is important for the university staff, the students and the accrediting authority. This issue requires the detailed consideration of all program and course designers. The standards should be developed appropriately and consistently in relation to the specification of the objectives for each course, and become the focus of all course assessment undertaken by their examiners. The record of their achievement would then comprise the evidence that is provided for inspection by the responsible accrediting committees.

It is now possible to identify that:

The first step towards Transformation is the adoption of the Washington Accord Graduate Attributes as the goals of each engineering education program to be realised by every graduate.

This implies that these attributes will guide and direct program design, and delivery. They will also lead to the specification of standards whose realisation by each graduating student will be evidenced by assessment. The focus on the achievement of the goals by every graduate is important, not only because it is the individuals that will become engineers (and their achievement of all the essential attributes is not guaranteed by examining a program holistically), but because it is important for the success of the student's educational experience. Monitoring their progress toward the achievement of their goals enables the assessment process to include an increased formative component as they progress toward their summative assessments. The educational experiences and the projects that the students undertake can be selected to overcome any shortcomings that may need to be corrected. It will also be suggested that the most appropriate technique for the development of clear evidence of the individual attainment of the required attributes is the student's e-portfolio (Section 5.6) which will include a record of the assessment of each graduate attribute.

4. A Review of Engineering Education

4.1 Engineering Education History

Engineering education has evolved to meet the developments in engineering described in Section 2.4. A summary of this development is presented in the Contributed Panel authored by Dr Tony Marjoram.

Contributed Panel No. 4:

A Perspective of Engineering Education: its History and its Role in National Development and a Sustainable Future

Dr Tony Marjoram

Engineering education began with the dawn of civilisation, as our human ancestors started to distinguish themselves in the animal world with the use, design, manufacture and innovation of tools, developing engineering and the passing on of engineering knowledge. Engineering education is therefore very much a part of human development and history, and indeed of the direction and pace of historical change. Engineering education is at the heart of the development of civilisation – the Stone, Bronze, Iron, Steam and Information Ages could not have developed and succeeded without the development of engineering and the passing on of engineering knowledge. The development of engineering education, as part of the emerging profession of engineering, began over 150,000 years ago, with the transfer of the skills of tool and weapon making. Military engineering was followed by civil engineering, with the need for defence and the development of early infrastructure.

The development of engineering education, from what was essentially the informal passing on of knowledge in an early form of mentor relationship, continued with the development of engineering knowledge and more formalised crafts and guilds. Simple, often patriarchal forms of engineering education in ancient societies developed into various types of vocational technical schools in the Middle Ages, particularly during the Renaissance and the scientific revolution of the 16th and 17th Centuries. Leonardo da Vinci, for example, who held the official title of 'Ingegnere Generale', produced notebooks reflecting an increasing interest in recording how things worked, and communicating this to others. Galileo Galilei developed the scientific approach for the understanding of the natural world and analysis of practical problems with mathematical representation, structural analysis and design – a landmark in the development of engineering and engineering education.

This approach was instrumental to and continued into the Industrial Revolution, which was powered by engineering knowledge, application and education, and developed rapidly in 18th Century England, transferring to Europe, North America and world. Machines replaced muscle in manufacturing, in a synergistic combination of knowledge and capital. The first Industrial Revolution took place from 1750-1850, focused on the textile and related industry. This wave of innovation and industrial development was the first of what have become known as Kondratiev waves, long waves, supercycles or surges in the world economy, consisting of alternating periods of high and low sectoral growth of around fifty years duration. Five major waves of innovation have been identified as part of the 'Schumpeter-Freeman-Perez' model. The second wave or revolution focused on steam and the railways from 1850-1900. The third wave was based on steel, electricity and heavy engineering from 1875-1925. The fourth wave was based on oil, the automobile and mass production, and took place between 1900-1950 and onward. The fifth wave was based on electronics, telecommunications and computers during the post-war boom from 1950. A sixth wave, based on new knowledge production and application in such fields as IT, biotechnology and materials, began around 1980. Most analysts accept this model, although the precise dates, phases, causes and effects of these major changes continue to be debated. It appears that the seventh wave will focus on sustainable 'green' engineering and technology, and can be seen to have begun, at least conceptually, around the time of the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, with more practical interest developing around 2005. Green technology was emphasised at the Rio+20 Conference in 2012, although engineering seems to have been overlooked, undervalued and marginalised yet again. As Beanland and Hadgraft observe, the six major waves of technological innovation have all been reflected in subsequent innovations and transformations in engineering education – it is therefore most timely to be considering transformations based on new knowledge production, application and sustainability.

Development of Engineering Education

The most crucial period in the development of engineering was the 18th and 19th Centuries – particularly the Iron and Steam Ages, the second Kondratiev wave of innovation and industrial revolution. Early interest in the development of engineering education began in the German mining industry, with the creation in 1702 of a school of mining and metallurgy in Freiberg. One of the oldest technical universities was the Czech Technical University in Prague, founded in 1707. In France, engineering education developed with the creation of the École Nationale des Ponts et Chaussées (established in 1747) and École des Mines (1783). The École Polytechnique, teaching the foundations of mathematics and science, was established in 1794, during the French Revolution – the revolution in engineering education itself began during a revolution. France developed the system of formal schooling in engineering after the Revolution, under Napoleon's influence, and engineering education in France has retained a strong theoretical and military character. The French model influenced the development of polytechnic engineering education institutions around the world at the beginning of the 19th Century, especially in Germany – in Berlin, Karlsruhe, Munich, Dresden, Stuttgart, Hanover and Darmstadt between 1799 and 1831. In Russia, similar schools of technology were opened in Moscow (1825) and St. Petersburg (1831), based on a system of military engineering education. The first technical institutes appeared at the same time in the USA – including West Point in 1819 (modelled on the École Polytechnique), the Rensselaer School in 1823 and Ohio Mechanics Institute in 1828. In Germany, polytechnic schools were accorded the same legal foundations as universities.

In England, however, following the early years of the Industrial Revolution, engineering education continued to be based on a system of apprenticeship with a working engineer – many engineers had little formal or theoretical training. Men such as Arkwright, Hargreaves, Crompton and Newcomen, followed by Telford, Maudslay, George and Robert Stephenson, all had little formal engineering education, yet developed the technologies that powered the Industrial Revolution and changed the world. In many fields, practical activity preceded scientific understanding – we had steam engines before thermodynamics, and 'rocket science' is more about engineering than science. England tried to retain the technological lead by prohibiting the export of engineering goods and services in the early 1800s. This is one reason why countries in continental Europe developed their own engineering education systems based on French and German models, with a foundation in science and mathematics, rather than the British model, based on artisanal empiricism and laissez-faire professional development. Through the 19th and into the 20th Centuries, however, engineering changed and with it engineering education. England was also obliged to change toward a science and university-based system. This reflected the rise of the 'engineering sciences' and the increasingly close connection between engineering, science and mathematics, and was partly due to fears in England of lagging behind the European model in terms of international competitiveness.

By the end of the 19th Century, most of what were becoming industrialised countries had established their own engineering education systems, based on the liberal, student-centred model introduced by Wilhelm von Humboldt at the University of Berlin, combining theory and practice, focused on scientific research. The German "Humboldtian model" went on to influence the development of universities in France and elsewhere, although the emphasis on practice as well as theory was often later overlooked. In the 20th Century, the professionalisation of engineering continued with the development of learned societies and the accreditation of engineers through qualification and continued professional development, with universities and professional societies facilitating education, research and the flow of information through journals, technical meetings and conferences. These processes continue with the development of international accords, standards and accreditation for engineering education, and the mutual recognition of engineering qualifications and professional competencies. These include the Washington Accord (established in 1989), Sydney Accord (2001), Dublin Accord (2002), APEC Engineer (1999), Engineers Mobility Forum (2001) and the Engineering Technologist Mobility Forum (2003), and the 1999 Bologna Declaration relating to quality assurance and accreditation of bachelor and master programmes in Europe.

Looking to the Future there is a need for Fun as well as Fundamentals

The Humboldtian model was transferred, innovated and developed with an increasing focus on theoretical foundation rather than student-centred practice, and may therefore better be described as neo-Humboldtian. The development of this model is also one of the factors that has led to the present day decline of interest in engineering at university level. The mathematical base became regarded as too abstract, out of touch, hard work and boring by many young people. This has lead to a questioning of the Humboldtian model, and, ironically, increasing interest in problem- and activity-based learning – which was part of the original theory/practice model of Wilhelm von Humboldt. The neo-Humboldtian model also underpins the “linear model of innovation” – the first and major conceptual model of the relation between research-lead science, technology and economic development. The linear model is based on the neo-Humboldtian notion that pure, disinterested, basic scientific research, followed by applied research and development, leads to knowledge applications, production, innovation and diffusion.

This model has become the accepted world view of innovation, due largely to its beguiling simplicity for the public and policy makers, and of course the support of the lobby for science funding. While the precise origins of the model are unclear, many accredit the emphasis of Vannevar Bush in 1945 on the role of science (rather than engineering) in wartime success, underpinned by statistics based on and reinforcing the conception of the linear model. The linear model became the paradigm for “science and technology policy” and post-war economic development, as embodied in the Marshall Plan and later the work on “science and technology” indicators by OECD and UNESCO, despite various critiques. Chief among these criticisms was the view that the linear model overlooks the role of engineering and engineering education in innovation. Science and technology indicators tend to overlook engineering, for example, in not differentiating and disaggregating data on science and engineering graduation, employment and research (where many engineers are actually doing science, while in the wider view many scientists are actually doing engineering). The linear model therefore gives a misleading and inaccurate picture of science, engineering and technology by largely overlooking the role of engineering in development, and in science and technology policy.

What is required is an accurate and up-to-date model more representative of actual and changing modes of knowledge production, application and innovation. Science and engineering are part of a system, combining research, application and innovation encompassing government, universities and industry, and an accurate model would be based on a systems conceptualisation of science, engineering, technology and innovation. The limitations of such an approach should also be recognised as in many developing countries, for example, a model of knowledge transfer, application and innovation could be more accurate and appropriate.

Science and engineering education need to be better based on such a conceptualisation, as does policy understanding of the role of engineering in development. There is a particular need to address neo-Humboldtian notions underlying the ‘fundamentals’ approach to engineering education as well as the linear model of innovation. It is clear that engineering education is no longer attracting enough students of appropriate entry standard, and that this is due to negative perceptions of engineering and engineering education. It is also clear that young people are more attracted to engineering education with a student-centred, problem and project based approach, focusing on engineering solutions. Engineering education needs to focus on the original theory/practice model of von Humboldt.

It is important to point out the weakness of the linear model of innovation and also to emphasise the contribution of engineering to development as much innovation comes directly from engineering. There is a need to develop science, engineering and associated policy studies to facilitate this, to encourage research to more precisely understand innovation and technology transfer, at all levels, especially in developing countries. In the development context, there is a particular need to put engineering on the development agenda by focusing specifically on the important role that engineering and engineering education plays in addressing the UN

Millennium Development Goals, especially poverty reduction, sustainable development, climate change mitigation and adaptation. Engineering education need to reflect the seventh wave of sustainable 'green' engineering and technology with a focus on environmental and eco-engineering and associated design, manufacturing and production, distribution systems and infrastructure.

The promotion of public and policy understanding and interest in engineering, will happen with the better appreciation of the vital contribution of engineering to development, sustainability and poverty reduction. This is facilitated by information, case studies, advocacy and the inclusion of engineering studies in educational curricula at all levels. At the university level, for example, there needs to be more promotion relating to the relevance of engineering to address contemporary concerns, and course content and project activity to link engineering education with society in the context of related ethical issues, sustainability and the improvement of the quality of life around the world. The success of such an approach is demonstrated by the growth of "Engineers Without Borders" groups around the world and activities such as the Daimler-UNESCO Mondialogo Engineering Award – which are attractive to students through their concern to address such issues. Such initiatives help enrolment, public awareness and policy implementation of the importance of engineering in social, economic, international and humanitarian development. Engineering has changed the world, but is professionally conservative and slow to change. To attract young people, and to help them face the challenges of the future, engineering needs to put fun back into the fundamentals of engineering education through the transformation of curricula and pedagogy, using information and experience in more active, project and problem-based learning, combining just-in-time theory with hands-on applications. In short, relevance works!

Engineering and Engineering Education in Development

Engineering has been closely linked to human, social and economic development throughout history. The history and pre-history of humanity – the way we live, interact with nature and each other, is very much also the history of engineering. The design, use and innovation of tools and technology has significantly influenced the direction and pace of change of human, social and economic development. Engineering and innovation underpinned the Stone, Bronze, Iron, Steam and Information Ages, beginning over 150,000 years ago – engineering is one of the oldest professions in the quest for defence and development of early infrastructure. Also the change from one Age to another was not because our ancestors ran out of stones, bronze, iron or steam. Engineers built the Pyramids, Angkor Wat, Borobudur, Machu Pichu, Great Zimbabwe, medieval cathedrals and associated civilisations, and drove the first Industrial Revolution, the five major waves of technological innovation over the last 200 years and the world we see today.

The first wave of the technological innovation and industrial revolution was based on the development of iron and water power. The second wave was based on the development of steam power, railways and mechanization, and the third wave on steel, heavy engineering and electrification. The fourth wave was based on the development of oil, automobiles and mass production, and the fifth wave based on electronics and computers. The sixth wave is based on new modes of knowledge generation, dissemination and application, knowledge and information societies and economies, in such areas as ICT, biotechnology, nanotechnology, new materials, robotics and systems technology, characterized by cross-fertilization and fusion, innovation, the growth of new disciplines and decline of old disciplines. The seventh wave of technological revolution may focus on knowledge, engineering and technology for sustainable development, climate change mitigation and adaptation. All waves of technological innovation and development are accompanied by new modes of knowledge that require new approaches to learning.

Amid these broader waves of revolutionary technological, industrial, social and economic development, engineering has also played a central role in the incremental development of infrastructure in transportation, communications, buildings, water supply, sanitation, energy generation, distribution and use. These development revolutions originated in Europe and spread around the world, initially in the periods of exploration and colonisation, later in trade and physical development – indeed, the concept of "development" and "developed" countries has been closely identified with the development of industry and infrastructure. Although many "developed" countries now have larger tertiary service sectors than secondary industry, and primary resource sectors, much of the service sector is also built and depends upon engineering and technology, as does the primary sector. The concept of development remains largely linked to the development of industry and infrastructure and standard of living, although it continues to be measured by such indicators as Gross Domestic Product, GDP per capita and, more recently, by the Human Development Index, HDI. Development may also be described, less euphemistically, as higher, middle and lower income countries. Models of development have also been constructed from the Western model of development in modernisation theory, dependency theory and World System Theory, although development continues to be defined mainly economically, rather than sociologically, politically or structurally and, along with GDP/capita, economic growth remains a dominant indicator. Industrialisation and import substitution continue to be key policy objectives, along with the enhanced provision of basic needs and, more recently, human and sustainable development.

Most models of development depend on engineering and technology transfer, not only in industry and infrastructure, but also to address basic needs and the UN Millennium Development Goals, particularly those relating to poverty reduction, sustainable development, and climate change mitigation. This includes technology transfer at lower as well higher levels, into, between and within developing countries. The importance of technological adaptation and development within developing countries also needs to emphasise technological appropriateness and "learning by doing". The focus of most universities in developing countries is upon education, with limited resources for research and development on local issues, problems and challenges. Many university staff members are trained in developed countries, and promotion is usually based on Western university models – for example on research and papers published, particularly in international journals on international issues. There is a particular need to promote research and development on local issues, with university cooperation and access to local communities.

These issues relate particularly to addressing basic needs, poverty reduction and sustainable development. The development and application of engineering and technological knowledge underpins and drives sustainable social and economic development. Engineering education is vital to provide the engineering and technology essential to address the basic human needs, poverty reduction and sustainable development, as indicated in the comments of world leaders on knowledge societies and economies, and in the declarations of international conferences and world summits. Despite this, however, engineering is routinely overlooked in the context of development policy and planning. It is hardly mentioned in relation to the Millennium Development Goals or in many Poverty Reduction Strategy Papers (PRSPs) which are strategy documents that aid donors and international finance organizations require from low income countries for them to receive debt relief and financial assistance.

Basic Needs and Poverty Reduction

The role of engineering and engineering education in addressing basic needs, poverty reduction and sustainable development is now considered in more detail.

Poverty is defined conventionally as living below US$2 per day, and extreme poverty as living below $1.25 per day. Poverty therefore relates particularly to the developing and least developed countries, although not exclusively so – there are examples of relative poverty in most cities and countries around the world. In 2012 the World Bank released data from a study over the period 2005-2008 indicating that, while absolute numbers had increased, the percentage of people living in poverty had declined for the first time since 1981, estimating in 2008 that 2.49 billion people lived on less than $US2 a day and 1.29 billion below US$1.25, down from 2.59 and 1.94 billions in 1981, respectively. The eradication of poverty, especially extreme poverty, is the first of the UN Millennium Development Goals (MDGs). Poverty depends on social and economic context and such issues as access to land and resources, and is a measure of income and resource distribution and inequality. Poverty is also gender related as 60 per cent of the world's poor are women, who are also, in many countries, mainly responsible for family care and services. While it is conventionally considered, measured and indicated financially, poverty relates essentially to the access of people to the resources with which to address their basic human needs, especially food. This depends on resource availability and population pressure – people living in poverty spend more of their income on basic needs such as food, and are especially vulnerable to increases in the cost of living. Poverty depends on natural factors such as drought and famine, and also on government policies regarding income and resource distribution. In the 1980s, for example, free market policies of economic liberalization and structural adjustment cut government support of social programs, subsidies and public financing in developing countries and led to an increase in poverty and a substantial increase in inequality within and between countries. In the context of access to resources, poverty is also defined as a denial of basic human rights in relation to food, housing, clothing, a safe environment, health and social services, education and training, decent work and the benefits of science and technology.

The access of people to the resources with which to address their basic human needs depends crucially on knowledge, and access to knowledge. The development of agricultural technologies in the Industrial Revolution revolutionized rural and urban productivity, even with increasing populations, and dramatically reduced poverty. This helped to break the perception that food shortages and poverty were an inevitable fact of life. Other areas of basic need include water supply and sanitation, housing, energy, transportation, communication, income generation, employment and enterprise creation. The application of knowledge in engineering, science and technology has been and will continue to be vital in addressing basic human needs and the reduction of poverty while driving economic and social development.

Engineering and technology consists of 'hardware', the tools, equipment and infrastructure, and 'software', the engineering knowledge that develops the technology that surrounds and supports people around the world. The application of engineering and technology helps address poverty at all levels. At the macro level, neo-classical and later economic growth theories paid increasing reference to technology and innovation as the main drivers of economic development and growth, and emphasize economic growth as the main factor in the reduction of poverty, despite criticism of the 'trickle down' effect. Recent research also indicates that growth does not necessarily reduce poverty, but also requires government policies that reduce inequality, with infrastructure playing a key role. Many businesses in developed and developing countries are medium and small-scale enterprises, employing less than 250 or fifty employees, and many more businesses are at the micro level with less than 10 employees. Around the world, especially in the developing and least developed countries, micro, small and medium scale enterprises (MSMEs) represent the vast majority of companies and jobs, up to 50 per cent of GDP, and higher growth compared to larger industries. Many MSMEs are also focused on particular technologies and innovations.

Technologies are most vital and visible in addressing basic human needs and improving the quality of life of ordinary people, through direct application at the community and family level, in both villages in rural areas and in urban communities. Engineering and technology is vital for the provision and development of food supply, production and processing, water supply and sanitation, waste disposal, housing, lighting, energy, transportation, communication, income generation, employment and enterprise creation. Examples include animal and engine powered farm machines, domestic food processing tools, equipment and techniques, the construction of wells, water tanks and improved toilets, better housing and cooking stoves, low-cost roads, solar-powered lighting and mobile phones. Technology and enterprise creates income and jobs. Technology for the poor does not have to be poor technology or low technology. One of the greatest challenges for the next generation of engineers will be to continue to address poverty. Engineering and technology need to be appropriate to the social, economic, educational and knowledge situations of people in order to facilitate them to address their own basic needs, alleviate poverty and promote sustainable livelihoods and development. This requires effective policy formulation, implementation, and the integration of engineering and technology into Poverty Reduction Strategy Papers. It also requires effective capacity and capacity building, and the education and training of young engineers, particularly those in developing countries, to be aware and sensitive to the role of engineering and technology in poverty reduction. Government ministries and departments, donor agencies, universities, NGOs and other relevant organizations need to be encouraged and supported in this process with the transfer of information and experience.

Engineering and Engineering Education in Sustainable Development and Climate Change

The world faces increasing challenges in relation to the need for development to be environmentally sustainable and to avoid the potential impacts of climate change. The use of resource needs to be sustainable for future generations, and we need to protect our environment from pollution and degradation. The use of natural resources has approached and exceeded critical limits in some areas, natural and man-made disasters appear to be more frequent, while the gap between the rich and poor countries continues to widen. These issues are a major threat to global prosperity, security, stability and sustainable development.

Engineering lies at the heart of sustainability, and sustainability is the major challenge for engineering. Most countries now recognize the need for sustainability and role of engineering and technology in sustainable development, and agree that there is an urgent need to reduce emissions and use resources more efficiently, if we are to mitigate and minimise the catastrophic effects of climate change. The question, amid increasing population pressures and consequently increasing consumption, is how to achieve this? This question was first raised in 1972, with the publication of "Limits to Growth" by the Club of Rome – which created major interest, concern and debate. Many countries recognized the need for policy instruments and initiatives for climate change mitigation and adaptation prior to the 2009 United Nations Climate Change Conference in Copenhagen, and similarly for sustainability prior to the UN Conference on Sustainable Development in 2012, although both COP15 and Rio+20 failed to deliver any binding agreements and were broadly disappointing for most, including the science and engineering communities, with engineering hardly mentioned at Rio+20 and in the associated documents. Addressing these issues, and the specific outcomes and follow-up to COP15 and Rio+20, will be one of the greatest challenges that engineering has faced. This will require the development of environmental engineering, the greening of engineering, and the need for the engineering community to ensure that engineering and technology are fundamental to the agenda for sustainable development and climate change mitigation and adaptation.

To enhance sustainable development and climate change mitigation and adaptation, significant investment in technology and infrastructure will be required. The use of coal may double by 2030, and so will the need to develop carbon capture and sequestration and related technologies. This will be a challenge on a scale similar to the development of the technology of the petrochemical industry. Many countries were looking to develop nuclear power generation, which will be equally challenging, as the nuclear industry has declined over the last decades in the shadow of Fukushima. New nuclear technologies which address its current limitations will be required. Renewable energy has developed over the last decade, and will need further development to reduce its cost. The same applies to other sectors, such as housing and transportation. Many new engineers will therefore be required, and the demand for engineers can only increase significantly. While increasing market demand will help attract young people into engineering, it takes over five years to develop courses and graduates, and over ten years to produce experienced engineers. Government support is urgently required for engineering curriculum development and associated engineering research, development and innovation. Although investment in current technology is a pressing issue, R&D for new technology is also urgent, and governments need to invest now to stimulate R&D and industry in the direction of the coming wave of essential technological development. Sustainable development, climate change mitigation and adaptation will need to be central in the engineering development agenda.

Engineering Capacity and Education Orientation

The Intergovernmental Panel on Climate Change (IPCC) has emphasised the importance of technology and finance in climate change mitigation and adaptation. Despite this, the role of engineering in sustainable development is often overlooked. At the same time, there is a declining interest and enrolment of young people, especially young women, in engineering. This will have a serious impact on capacity in engineering, and our ability to address the challenges of sustainable development, poverty reduction and the other MDGs. The most pressing challenge for the engineering profession is to ensure that there are enough appropriately qualified and experienced engineers to meet this demand. This will require the development of new, more interesting and hands-on courses, education materials and systems of accreditation featuring sustainability. Young people will hopefully be attracted to such courses, which will raise overall awareness of the role and importance of engineering in sustainable development, at the centre of building a carbon-freer future.

How can we promote the public understanding of engineering, and the application of engineering in sustainability? It appears that the decline of interest and entry of young people into science and engineering is due to the fact that these subjects are often perceived by young people as nerdy, uninteresting and boring; that university courses are difficult and hard work; that jobs in these areas are not well paid, and that science and engineering have a negative environmental impact. There is evidence that young people turn away from science at the age of around 10, that good science education at primary and secondary is vital, as science teaching can turn young people off, as well as on, to science and engineering. We need to show that science and engineering are inherently interesting and to promote public understanding by illustrative examples of this, to make education and university courses more interesting, and with appropriate salary scales (although this is already happening with supply and demand).

Public understanding and interest in engineering is facilitated by an appreciation of engineering as a part of the problem-solving solution to sustainable development and climate change mitigation. University courses need to be more interesting with the transformation of curricula and pedagogy and the use of less formulaic approaches that turn students off, with more activity, project and problem-based learning, just-in-time approaches to learning and hands-on applications relating to sustainable development. These approaches promote the relevance of engineering, address contemporary concerns and help link engineering with society in the context of sustainability, building upon rather than displacing local and indigenous knowledge. Relevance is an essential component of effective engineering education! It is apparent that these challenges are linked in a possible solution – many young people are keen to promote sustainable development and climate change, and address other international issues such as poverty. They are attracted to engineering when they see engineering as part of the solution. Engineering has changed the world, but it is a conservative profession that is slow to adapt to the changes that it has been responsible to implement! We need innovative examples of schools, colleges and universities around the world that have pioneered activity in such areas as problem-based learning. Engineers introduced just-in-time techniques in industry, and now need to do the same in engineering education.

The transformation of engineering education needs to respond to the rapid changes in knowledge production and application, by emphasizing a cognitive, problem-solving approach, synthesis, awareness, ethics, social responsibility, experience and practice in national and global contexts. Engineering education needs to emphasise the importance of lifelong and distance learning, continuous professional development, adaptability, flexibility, interdisciplinarity and multiple career paths, with particular reference to socially responsible engineering and sustainability. This is important because, while the need for holistic and integrated systems approaches in engineering have been recognised and spoken about for some time, there is still a need to share information on what this means in practice, and to share pedagogical approaches and curricula developed with this focus. The sharing of experience is particularly important for universities and colleges in developing countries, who face serious constraints regarding human, financial and institutional resources to develop such curricula, learning/teaching methods and materials. Such a transformation of engineering and engineering education will be essential if engineering is to catch the "seventh wave" of technological revolution in innovation for sustainability.

The development and application of knowledge in engineering and technology is vital for sustainable social and economic development, climate change mitigation and adaptation, the promotion of international cooperation and the bridging the "knowledge divide" in this area. A major challenge facing the engineering profession is to position itself at the centre of the sustainable development and climate change mitigation agendas, and at the same time position sustainable development and climate change mitigation as a central agenda for engineering education. An important contribution to the ongoing "Limits to Growth" debate in 1997 was the publication of Ernst von Weizsäcker's "Factor Four: Doubling Wealth, Halving Resource Use". The debate has intensified with increasing concern over climate change, reflected by the interest of politicians around the world in a "green new deal" to help lift economies out of recession. Von Weizsäcker and the Natural Edge Project have recently shown that engineering and innovation makes it possible to improve resource use and wealth creation by a factor of five in "Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity". It is hoped that such material will promote political will and behavioural change toward a new wave of green engineering and technology.

4.2 Engineering Education Today

A very thorough, comprehensive and independent study of engineering education in leading universities in USA has recently been completed and published by the Carnegie Foundation for the Advancement of Teaching [32]. It was conducted as part of their program which examines how the members of various professions are educated for their responsibilities in the communities they serve. We strongly recommend its consideration by those considering the future directions for engineering education or planning new programs. While its findings are derived from the observation of universities in USA, there is no reason to doubt their general applicability. Their findings are salutary:

- "Undergraduate engineering education in USA is holding on to an approach to problem solving and knowledge acquisition that is consistent with practice that the profession has left behind."
- "There are, however, pockets of innovation, and these, along with the example of medical education and new findings from the learning sciences, suggest to us that engineering educators can transform their programs so that students' learning experience more effectively prepares them to meet the new demands of professional practice."
- "Concerns with ethics and professionalism, which have new urgency in today's world, have long had difficulty finding meaningful places ... for not only are programs packed solid with the technical courses, but also there are limited conceptual openings for issues of professionalism."
- "The dominant curriculum model, which might be best described as building blocks or linear components, with its attendant deductive teaching strategies, structured problems, demonstrations, and assessments of student learning does not reflect what the significant and compelling body of research on learning suggests about how students learn and develop and how experts are formed."
- "The tradition of putting theory before practice and the effort to cover technical knowledge comprehensively, allow little opportunity for students to have the kind of deep learning experiences that mirror professional practice and problem solving."
- "The laboratory is a missed opportunity: it can be more effectively used in the curriculum to support integration and synthesis of knowledge, development of persistence, skills in formulating and solving problems, and skills of collaboration."
- "Design projects offer opportunities to approximate professional practice, with its concern for social implications, integrate and synthesise knowledge, and develop skills of persistence, creativity, and teamwork. However, these opportunities are typically provided late in the undergraduate program."
- "Students have few opportunities to explore the implications of being a professional in society. Moreover, the work of providing such opportunities is often outsourced to other academic units."
- "If students are to be prepared to enter new-century engineering, the centre of engineering education should be professional practice, integrating technical knowledge and skills of practice through a consistent focus on developing the identity and commitment of the professional engineer."
- "The current linear components structure will not support such a focus, for it is not a matter of making room for more attention to lab, design or ethics, or even using more effective teaching and assessment strategies for these components. A focus on professional practice will require **remaking** undergraduate engineering education, networking the components in ways that strengthen and connect them into a cohesive whole. This would be accomplished through a set of design principles that represent the best of current understanding of the learning sciences and medical education, and by using teaching strategies that support the integration of knowledge and skills and engaged learning."

These extracts illustrate the perception and pertinence of the author's work. They have thoughtfully evaluated our current system of engineering education, highlighted its short-comings and constructively outlined some principles to guide engineering faculty toward the realisation of improved effectiveness. They "recommend that professional schools, because they are responsible for the preparation of practitioners, should aim for an increasingly integrated approach to the formation of student's analytical reasoning, practical skills and professional judgement. Although some engineering schools have introduced programs, teaching methods, or curriculum structures that attempt to integrate these professional goals, none offers a comprehensively networked approach."

It should be noted that their recommended focus on professional formation is consistent with the intent of the Washington Accord graduate attributes and also with the views expressed by employers in relation to their expectations of engineering education.

4.3 Is a Transformation Required?

As noted previously there have been many calls for the transformation of engineering education including a number of major reviews that have come to this conclusion.

The Royal Academy of Engineering in the United Kingdom has produced a very detailed study of the issues involved in "Educating Engineers for the 21st Century" [33]. The major findings of their research include:

- Universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enabling students to gain practical experience of industry as part of their education.
- The accreditation process for university engineering courses should be proactive in driving the development and updating of course content rather than being a passive auditing exercise.
- The funding and ranking driven focus on research in many universities is constraining the development of innovative learning and teaching of engineering.
- Engineering courses at the UK universities are now seriously under-funded.
- Reform of the engineering qualification system at a European level must be focussed on the importance of output competence as the primary means of assessing educational achievements.
- Much more needs to be done to ensure that school students perceive engineering as an exciting and rewarding profession that is worth pursuing.
- Unless action is taken a shortage of high calibre engineers entering industry will become increasingly apparent over the next ten years with serious repercussions for the productivity and creativity of industry.

As mentioned above, The Carnegie Foundation has recently called for the transformation of engineering education [34] following the study discussed in Section 4.2 [32]. They call for a new model of engineering education, because "in the midst of a profound worldwide transformation in the engineering profession, US undergraduate engineering education is holding onto an approach to problem solving and knowledge acquisition that is consistent with practices that the profession has left behind. Specifically, undergraduate engineering education in the United States emphasises primarily the acquisition of technical knowledge, distantly followed by preparation for professional practice. We are calling for a new model that will involve fundamentally rethinking the role and even the makeup of the faculty." They proceed to conclude [34] "we are not persuaded that incremental improvements to the current model will result in engineering education that is aligned with the work of and demands on the new-century engineer." There are also many papers, books and articles that address the subject and highlight the need for change [25] [35] [36].

Dr. Moshe Kam, the 2011 President of IEEE, says [37] "engineering education must undergo significant transformation in the next decade to continue to push innovation forward, or global economic expansion will slow. Kam believes engineers of all disciplines need a deeper understanding of computing and networking, cross-disciplinary education, and sharper analytical skills. He warns that the current pace of technological innovation is not sustainable without further changes to how we prepare tomorrow's engineers. Challenges, such as providing sustainable energy and universal access to health care would require a much more versatile and adept engineer than the typical graduate we educate now."

The concerns expressed are quite diverse. They focus upon the perceived problems with the current education system, which is considered to be unresponsive and relatively homogeneous. The most evident issues are:

- Concerns about the quality of graduates and their relevance to a changed profession,
- Concern about the continuing focus on technical knowledge resulting in a deficiency in graduates of the broader personal skills and perspectives that are essential in engineering practice,
- Insufficient graduate engineers with the knowledge and skills to drive innovation,
- Lack of interest of students in undertaking engineering,
- Inadequate attention to the development of the professional practice elements of engineering,
- Academic staff without experience of engineering practice,
- Inadequate exposure of engineering students to people with practical engineering experience,
- High failure rate of students in engineering program,
- Low participation rate of female students,
- Lack of technical breadth created by the narrow technical focus of current programs,
- Insufficient focus upon broader engineering systems and professional issues,
- The need to more appropriately consider the environmental issues associated with engineering practice,
- The need for change from a teacher-centred to a learner-centred educational paradigm,
- Limited utilisation of new technology to enhance the education program,
- The need to relate the student experience to the role of engineers,
- Loss of engineering graduates to other professions.

These issues, concerns and problems are quite generally applicable to the majority of engineering education programs. They are numerous and complex. They demand attention and action. They are consistent with the conclusions drawn throughout Section 3 that the specified graduate attributes are not being realised. There is a relatively consistent pattern of program structure and presentation in engineering education which has become established across universities and the absence of competitive approaches, with the exception of a limited number of progressive institutions, acts to diminish the necessity for change.

It is widely accepted that change is difficult to achieve in academic institutions. While there are many forces resistant to change in universities that need to be overcome for transformation to be implemented, there is also goodwill to consider changes that can be demonstrated to be justifiable. The difficulty of achieving change cannot be used as a reason to justify widespread failure to address fundamental problems associated with the design and delivery of a core activity.

Engineering education should be one of the most popular educational pathways for young people seeking to enter an interesting, essential, satisfying and important career. The fact that it is not, should challenge everyone with a role and responsibility in the profession to support the realisation of change as a matter of urgency.

While the need for transformation has been identified and well defined for many years [37] the challenge to achieve transformation, with very few exceptions, lies ahead. However, many of the elements of the necessary transformation have been identified and explored. The approach of Franklin W. Olin College of Engineering, explored in Section 4.6.3, is exemplary. Also the CDIO strategy, discussed in Section 4.6.5, has been a vehicle for transformation. The support provided by the National Science Foundation (NSF) in USA has also been very significant and provided many insights into the difficulties associated with the development of effective collaboration [38]. The National Academy of Engineering (NAE) has also assisted through a series of initiatives that are discussed in the Contributed Panel authored by Dr Norman Fortenberry and Dr Elizabeth Cady. The NAE Report on Educating the Engineer of 2020 [39] is a major source of information relevant to the implementation of change in engineering education. President Emeritus of MIT, Charles Vest, writing on the same topic [40], concludes "that making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details."

The activities of the University of Illinois at Urbana-Champaign "iFoundry for Innovation in Engineering Education" [41] are also noteworthy. It is significant that Franklin W. Olin College of Engineering and the University of Illinois at Urbana-Champaign recently formalised a Memorandum of Understanding [42] that states "… inasmuch as both institutions understand the importance of transforming the nature of engineering education to match the opportunities and challenges of the 21st century, Olin and Illinois agree to work together to further fundamental, principled and widespread change in engineering education … and agree to work to form a large, national and international alliance of like-minded schools and colleges of engineering to promote curriculum transformation around the country and around the globe …" This is a welcome, appropriate and highly commendable action by these two institutions to facilitate the development of the momentum required for transformation. The task is so large that cooperative collaboration is essential. Their successful example of a new approach will be inspiring. It is, of course, possible for all universities to create benefits from collaboration as the opportunities are plentiful. However, it is unfortunate that the traditional concept of academic rivalry has proved, in the case of engineering education, to be a constraint upon the realisation of both the essential transformation and institutional collaboration. In this century there is much to be gained from cooperation as will be seen from the exploration of this issue in Section 6.

It is now possible to identify that:

The second step towards Transformation is to design the curriculum to maximise the development of the capabilities that are essential to operate as a professional engineer.

This principle is closely related to the first as the Washington Accord graduate attributes define the capabilities essential for operation as an engineer.

Contributed Panel No. 5:

NAE's Re-engineering of Engineering Education

Dr Norman Fortenberry and Dr Elizabeth Cady

Respectively, Executive Director ASEE and Program officer NAE/CASEE.

The United States National Academy of Engineering (NAE) was created as a separate Academy in 1964 with the mission of "advancing the nation's technological welfare." It has recognized almost from the beginning that attention to education was a critical part of this mandate. Operating within the context of its role as an advisor to the nation, NAE engaged its members to participate in the conduct of a series of studies between 1985 and 1988 examining engineering education and practice[1], engineering technology education[2], undergraduate engineering education[3], and career long education of engineers[4]. In 1995, the NAE actively participated in studies of restructuring undergraduate engineering curricula to respond to the emerging economic and social realities of the 21st Century[5]. Nine years later, NAE released The Engineer of 2020[6] which explored in greater detail the operating environments for future engineers, and Educating the Engineer of 2020[7] which explored in greater depth needed changes in the system of engineering education to better prepare future engineers to the realities of the 21st Century. More recently, NAE issued a workshop summary on lifelong learning[8] to lay the basis for an effort to update the 1988 report on career long learning.

In addition to its role as an advisor, the NAE has also sought to actively engage the engineering community through direct action. In 2004, NAE announced the selection of three senior fellows to explore key research questions in engineering education. Thus far, there have been nine senior fellows (including Walter Robb Senior Fellows and Boeing Senior Fellows) who along with five scholars-in-residence (since 2003) and thirteen (since 2005) postdoctoral scholars have been part of NAE's effort to work in collaboration with the engineering community to better characterize and optimize systems of engineering education. NAE has also sought to translate research findings into improved educational practices in classrooms and worksites through in-person seminars and textual research-to-practice briefs that seek to explain to engineering faculty and academic administrators how engineering education research findings can improve student learning, student retention, academic engagement and instructional effectiveness. It has also sought to translate research findings into more effective strategies for recruiting and retaining women into engineering majors.

NAE recognizes that engineers must not only be prepared to address technical challenges, but to think through the ethical and society implications of the choices that they make. In reports issued in 2004[9] and 2010[10] NAE has also looked at the increasingly complex ethical challenges facing engineers, not only at the individual level, but at the level of the profession itself. Work continues looking at specific cases of the engineering ethics related to climate change as well as energy extraction and use.

A key enabling strategy to enhance collegiate level engineering is to address the instructional knowledge and skills of engineering faculty. In 2009, NAE began the Frontiers of Engineering Education programs as a means to recognize and encourage innovations in curricula, pedagogy, laboratories, and uses of learning technologies by faculty in the first half of their careers. A two day symposium allows faculty nominated by NAE members and engineering deans to share innovative instructional strategies and techniques. However, NAE recognizes that faculty attention to instruction, particularly at research universities, will be highly influenced by systems of faculty recognition and reward. One complaint has been that instructional activities are not highly valued because they are not assessed in as straightforward a manner as traditional engineering research activities. To address this concern, NAE issued a 2009 report on evaluating engineering instruction[11]. The assumption is that once it is relatively easy to assess engineering instruction, use of such assessments will become more routine and widespread.

In recent years, NAE has recognized that attention to engineering education cannot be restricted to the undergraduate and graduate collegiate levels. In 2009, it issued a report[12] that sought to characterize status and prospects of engineering in K-12 education and followed this with a 2010 report[13] on the value and feasibility of developing content standards for engineering at the K-12 level. NAE has also engaged in direct outreach to pre-college populations with web sites targeting middle school <http://www.EngineerGirl.org> and high school girls <http://EngineerYourLife.org>.

Somewhat related to engineering at the K-12 level is the issue of thinking through how best to communicate to the general public what engineering is and what engineers do. In 2002, NAE issued a report[14] explaining why technological literacy was a necessity for all citizens in modern societies. Having established the importance of technological literacy, the NAE followed up with a 2006 report[15] on how best to assess for such literacy in order to gauge progress toward the goal of a technologically literate populous. In 2008, NAE issued a report[16] about the types of messages that were most likely to enhance the awareness of various population segments regarding the excitement of the promise of engineering and engineering careers. A web site (http://www.engineeringmessages.org/) now provides practical guidance to others interested in using such messages. In 2009, NAE built on the knowledge base developed in its work on messages in order to announce the Grand Challenges of Engineering www.engineeringchallenges.org/ as a way to capture the popular imagination about the importance of what engineers do to general health, happiness, and welfare.

Editor's Footnote: Dr Fortenbury's contribution to this article was made while he was Executive Director of NAE.

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4.4 Engineering Education Stakeholders

To achieve a transformation of engineering education in established and conservative institutions, the complex issues involved must be considered comprehensively and thoroughly to enable an alternative approach to be justified. This requires the total system of engineering education to be considered.

Let us first review who the stakeholders are and their various perspectives and considerations.

Parents: The majority do not know much about engineering as a profession for their children and would probably prefer that they studied medicine, law or business as they have heard that engineering courses are difficult and that the remuneration is only average. Parents with an engineering or technical background are more likely to be supportive of their children pursuing an interest in this discipline.

Potential Students: Are not usually interested in studying engineering unless they are above average performers in mathematics and enjoy technical topics including computers. They may know previous students who were good at mathematics and were not successful when they undertook an engineering program. They are unlikely to have a detailed understanding of engineering. They are often motivated to choose a career that can benefit the community and the world. They seek to make a difference. However they are unlikely to be aware that engineering provides a suitable vehicle for the fulfilment of that objective, as the engineering profession does not project a sufficiently positive image of itself as the provider of benefits to society. This is an opportunity lost as potential students should be receiving a message that an engineering career provides an opportunity to contribute through the responsible design and development of infrastructure, achieving a sustainable environment, assisting development in developing countries, and providing innovations in all types of fields such as transport, energy, medicine, computing and communications. Engineering needs to focus upon this group, both male and female, with a strong positive message, emphasising that it has a socially and environmentally responsible mission, that it is essentially global in its impact and opportunities, and that it is not just another component of commercial development. If female, they are likely to be uncertain that it will provide an accepting and satisfying work environment and it is important to address this issue also, preferably by giving examples of exemplary employment conditions and outcomes for females in engineering companies, Potential students do not understand that the skills and capabilities developed during an engineering program can lead to a wide variety of interesting and significant career roles that are equally valid for, and indeed require, both males and females.

Secondary Schools: The preparation for entry to a university course in engineering or science is obtained in the program of the secondary school system. Both engineering and science require a foundation of skills in mathematics and science to be established. However, in many school systems an interest in these fields of study is quenched by the inability of the secondary schools to make these subjects interesting and relevant. Consequently this inadequacy becomes a factor in students failing to be attracted to these careers. The inherent excitement and challenge of these subjects would be conveyed if there were more teachers of these subjects had qualifications and experience in the engineering and science professions.

Students: Usually they find the first section of the engineering degree program demanding and boring. They are surprised that the technological communication and information systems that are fundamental to their daily lives are not utilised very effectively in the university environment. They do not necessarily have a strong career commitment at the commencement of their study program, as they do not understand what an engineer does in any depth until later in their study program. Their interest in engineering, and consequently their motivation, is unlikely to increase until the program becomes relevant to their perceived professional role. The identification of a particular field of engineering specialisation evolves with exposure to the disciplines. They are not likely to rate their course very highly when they complete course performance surveys. The students are the primary clients of the institution, but to the student, universities seldom demonstrate the attributes of a client-focussed organisation. Their potential for independent learning is not fully utilised. The work areas for students at university are often not very appropriate to their needs. Their potential for learning from each other and working in teams is not maximised.

Academic Staff: They are likely to have done well in their engineering degree program and then progressed to post-graduate studies. They will have specialised in a relatively narrow aspect of engineering, which is complemented by their general engineering knowledge. Unfortunately it is increasingly unlikely that they will have had any significant experience as a staff member in an engineering organisation. They are likely to have been selected for an academic position on the basis of their research record, experience or potential. They are unlikely to have had any experience as an educationalist before joining a university, and may be more interested in research than teaching. Their incentives, in relation to promotion, will be biased towards the creation of a record of research publication and grant attraction. There is little incentive to initiate significant change or improvement in the educational experience of the student as the traditional lecture method is the most convenient vehicle for the delivery of their teaching responsibilities, it is the method that they are familiar with, and it probably represents standard practice in their institution. They operate within a system that is staff focussed and are normally comfortable about adopting the established norms. In university culture the academic staff are the key people in the university; the students are fortunate to be able to access the mysteries of engineering via their wisdom and experience. Each academic has a high degree of autonomy and questions any changes that would reduce it.

Academic Managers: They are concerned with the establishment of process for the ordered conduct of their unit and its fair and appropriate implementation. They understand the perspectives and preferences of academic staff and are unlikely to challenge their views and the status quo. Expensive development or improvement strategies are unlikely to be strongly encouraged. Developments and policy changes are likely to require evidence of staff support. The reputation of their group is important and as more status is attached to research developments that attract resources and deliver publications, research is normally considered to be of greater importance than educational delivery and developments. New courses may be of more interest than course transformation as they are easier to achieve and they are usually associated with expansion and influence. Promotion of their staff is usually related to research achievements as educational contributions are more difficult to ascertain and the judgements made in that area could be controversial. They will be concerned about cross-university relativities and be concerned about the apparent relative funding and status of their group.

University Leaders: If they are not engineers, the specific discipline issues and the significant differences associated with engineering education are unlikely to be fully appreciated. They are likely to delegate any program and academic discipline issues to the sub-ordinate responsible manager. Concepts of transformation may be seen to imply existing deficiencies rather than be seen as opportunities for enhancement of effectiveness. Consequently they are viewed as risky and receive a low priority. Any plans to initiate change would require the commitment of the Academic Managers, sources of funding, inclusion in university plans and evidence that it would not damage the reputation of the university or any of its performance parameters.

University Governance: University governance is focussed on general strategic directions, business plans, government relations, performance against targets, financial health, status accorded to the institution by the community, institutional competition, public relations, marketing, fund raising and external relations. In multi-disciplinary institutions they are unlikely to enter into the domain of academic performance and achievement unless a particular problem was identified externally.

Engineering Graduates: They are keen to see the reputation of their university maintained. Usually they have positive goodwill towards their alma mater, but are not often utilised as an effective resource. As a result of their experiences, they have very good insight into potential and desirable improvements and are a most valuable source of feedback, especially after they have obtained some employment experience. They could be also used to provide valuable experience, through sharing their knowledge, bringing understanding of the engineering profession, what it does and how it does it, to the university and its students. They can be a source of project ideas, provide mentoring, arrange work experience and provide evaluation of the student's attributes for the university. They could also be a source of learning facilitators to the student learning community (Section 7.3). There is enormous potential to involve this group in the process of transformation of the engineering education experience. Universities are more likely to see them as a potential source of financial assistance.

Practising Engineers: Are committed to their profession, but often quickly lose close contact with their university, although interaction may be maintained with one or two staff members with whom they had developed a special relationship. Generally they do not maintain close contact with universities unless a joint project is initiated by their employer with the university. However they are a potential asset to assist engineering education programs to better prepare undergraduates with appropriate capabilities for entry to the profession.

Employers: While they are key stakeholders as major beneficiaries of the university's programs, they seldom have close relationships with the universities. Some will have a symbolic advisory role, but there is seldom the depth of partnership that could be reasonably expected to exist between a supplier and a major beneficiary. A defined and organised commitment to a meaningful partnership should be the norm rather than the exception. Employers are generally seeking a transformation in engineering education, but the universities have not been listening. They have always projected a need for the development of the personal attributes, capabilities and skills in association with an ability to learn in an environment where technology has a relatively short lifecycle [43]. The active participation of professional engineering organisations and academies, as representatives of the employers and the community, will be required if the implementation of change is to be achieved.

Professional Organisations and Academies: The engineering graduates qualify to become members of these organisations when they have met the specified experience and professional development criteria. They tend to be more focussed upon the professional members and technological topics than their academic members. However they are interested in the research activities of universities and student member activities. They are often dependent on universities to provide frontier presenters. They are often reluctant to deal with policy issues that impact universities and their educational programs. This is because many members are not familiar with educational issues and educational politics, while those who are would prefer that the organisation did not become involved. Also, the academic members may come from various competitive universities, and the intervention of the professional body could require considerable delicacy. They can have significant impact as authoritative bodies, and could also assist universities by bringing the reality of the engineering profession to the universities, their students and staff, as well as to the government, the community, parents and future students. They have not been universally successful in bringing a clear understanding of the engineering profession to the community

Accreditation Authorities: While accreditation may be the responsibility of the previously discussed professional organisations, this responsibility is usually considered separately from their learned society obligations. Many accreditation authorities have been involved in implementing the new paradigm of (Washington Accord) graduate attributes and the performance criteria required for the registration of engineers. These are quite widely supported. They are responsible for the accreditation of all university engineering programs against these criteria. However, in view of the widespread calls for transformation of engineering education, the process of assuring that the specified attributes have been achieved by all graduates, as is constitutionally required, is clearly deficient. Rectification of this deficiency is essential to achieving any widespread transformation of engineering education. This will be discussed in detail in Section 10.3.

Government Bureaucrats, Departments and Ministers: There is a need for many more engineers in these roles and organisations, as the business of government involves the planning and delivery of services and projects that are complex and are critically dependent upon technology. The deficiency of technological expertise in government and the bureaucracy has become critical in many countries when the range of government responsibility is considered. There is inadequate professional engineering understanding and expertise available to enable their responsibilities to the community to be delivered competently, efficiently and economically. Governments will also be involved with many universities as funding providers, policy determiners, and as possibly as establishers of targets for student participation in particular disciplines, including engineering. They often initiate and/or fund inquiries into various aspects of university operations. They will also establish policies that impact directly upon university activities and may affect program standards and quality assurance processes. They are likely to be major funders of university research.

As the availability of an adequate number of appropriately qualified engineers is of major significance for the operation and development of every country, governments should be highly concerned with the current situation where the vast majority of countries face an under-supply of engineers and that a transformation in engineering education is considered essential for the rectification of this and other important problems. This is an operational, economic and strategic issue for governments as we are increasingly dependent upon the application of technology for the operation and development of our societies. Governments have a responsibility and a requirement to facilitate changes that enhance the effectiveness of engineering education in the interest of their citizens.

4.5 Engineering Education as a System

In essence the engineering education system is extremely simple. Students are exposed to a variety of educational experiences over a period of time until they are considered to have attained all of the attributes necessary to be certified as an engineering graduate and are permitted to obtain employment as an engineer. Unfortunately everything that flows from this simple concept is complex! Each university has its own framework, culture, objectives, policies and constraints, within which these various experiences are organised, delivered, undertaken and assessed. The outcome standards, as specified by the attributes to be possessed by each graduate, are generally agreed, as discussed in Section 3, but subject to very different interpretations by each department, program and staff member. Programs are typically of four years duration, but may be three or five years depending upon the foundation studies of the student and the nature of the program.

The variables which can determine a successful educational experience are numerous and include:

- Program design
- Curriculum details
- New Pedagogy
- Facilities
- Assessment methods
- Text and reference materials
- Information system
- Laboratories and workshops
- Learning spaces
- Academic staff
- Technicaministrative support
- Student support
- Computer systems
- Quality control
- Work experience
- Funding available

In addition to these quantifiable topics there are also important issues that are not readily quantifiable such as staff attitude, culture, ability, character, commitment and availability. However, as noted above, it is the student that is, or should be, the important focus of the system. It is the student, their experiences and their achievements that can result in the creation of an engineer. This means that the system has another series of factors that relate to each individual student:

- Prior knowledge
- Academic record
- Attitude
- Motivation
- Commitment
- Interaction with student colleagues
- Friendships
- Family support
- Financial resources
- Personal circumstances
- External activities/distractions
- Time availability
- IT facilities

These factors are less tangible, but no less important, and also need to be considered as they impact engineering education design and delivery. While selection of students is primarily based upon their previous academic record, motivation is likely to be the most critical factor in determining a student's successful realisation of their goal. Also it is important that course design should be arranged to be interesting and to enhance motivation as this will be of critical significance in facilitating student development and reducing student failure.

The design of a transformational engineering education requires a holistic, student focussed perspective that acknowledges the changes that have occurred in engineering, the employer's perspective of what is desirable and importantly the graduate attributes that are essential. An engineering college seeking to achieve this transformation must address the perceived deficiencies identified in Sections 4.2 & 4.3. Transformation begins with the establishment of clear objectives. The variables that can be utilised to achieve their realisation include:

- Program and curriculum modification
- New pedagogy such as project based learning and student centred learning
- New technology in the learning process
- Learning communities and team based activities
- Different learning spaces and facilities
- Revised laboratory programs
- Changed student assessment practices
- Integrated work experience
- Collaboration between universities
- Encouraging international exchange experiences
- Changed staffing strategies
- Staff training in educational practice
- Quality management systems

4.6 Examples of New Approaches to Engineering Education

4.6.1 The Synthesis Coalition

The Synthesis Coalition [44] was a union of eight diverse institutions: California Polytechnic State University at San Luis Obispo, Cornell University, Hampton University, Iowa State University, Southern University, Stanford University, Tuskegee University, and the University of California at Berkeley. This group was funded by the US National Science Foundation to design, implement and assess new approaches to undergraduate engineering education that emphasize: multidisciplinary synthesis, teamwork and communication, hands-on and laboratory experiences, open-ended problem formulation and solving, and examples of "best practices" from industry. They shared a belief that most engineering education programs were overburdened with course requirements, excessive compartmentalisation, and general lack of excitement and motivation. Consequently the Coalition seeks to restructure engineering education [45] by developing, experimenting with and evaluating the effectiveness of a variety of innovative curricula, delivery systems, settings and pedagogies. This has resulted in the NEEDS digital library [46] which is a valuable resource that can enhance engineering education. It is discussed more fully in Section 5.7.

4.6.2 The Gateway Coalition

The membership of the Gateway Coalition is Columbia University, Cooper Union, New Jersey Institute of Technology, Drexel University, Ohio State University, Polytechnic University and University of South California. It was established in 1992, also with NSF support. Their goal was to change the way they conduct the engineering educational process, through using embedded technologies to make the educational environment more exciting and more effective, and by developing a curriculum based on the ABET 2000 Attributes. (These subsequently evolved into the Washington Accord attributes.) It aimed [47] to develop collaboration in the areas of assessment, instructional technologies, professional development, under-represented populations, curriculum development and improvement, linking and sharing. Unfortunately this cooperation does not appear to have been sustained.

The NSF also established 6 other Coalitions with similar objectives of achieving changes which would enhance engineering education. While there was goodwill and cooperation during the funded development phase and some formal structures remain, the concept of cooperative sharing of new developments between universities faces many difficulties at the implementation phase, unfortunately.

4.6.3 Franklin W Olin Engineering College

This College provides an exemplar of an effective approach to engineering education. It has been established [48] to explore the transformation of engineering education and seeks to give priority to the development of the non-technical characteristics required by engineers through an emphasis on innovative projects throughout the program. Its brief, but highly successful, story is presented in the Contributed Panel authored by the College President Professor Richard Miller.

Contributed Panel No.6:

Comprehensive Redesign of Undergraduate Engineering Education at the Franklin W. Olin College of Engineering

Professor Richard K. Miller[1]

The F.W. Olin Foundation of New York chartered Olin College in 1997 to *"… become an important and constant contributor to the advancement of engineering education in America and throughout the world…"* With a total investment of nearly $500 million, their purpose was to produce a new paradigm for educating leaders in the 21st century by starting over in higher education and creating an entirely new institution with an intense student-centred focus, no academic departments, no tenure for faculty members, and large merit-based scholarships that reward bright young students who choose to devote themselves to the study of engineering. The Foundation had a proud legacy in philanthropy in higher education, donating funds to build 78 academic buildings on 58 university campuses over a period of nearly a half-century. However, they decided to end their building grants program and devote essentially all their remaining resources to the establishment of a new engineering college[2] in order to address widely recognised concerns in the U.S. about the need for systemic change in undergraduate engineering education. These concerns motivated the U.S. National Science Foundation to invest more than $100 million in the Engineering Education Coalitions Program in the 1990s in order to provoke systemic change on many university campuses. (The ambitious EECP program fell short of expectations, however, since established universities proved naturally slow or resistant to make fundamental changes.) The persistent concerns about needed improvements also resulted in several publications by the National Academy of Engineering which outline these concerns in some detail.[3]

These studies point to the need for engineers to be better prepared in the areas of teamwork, leadership, design and creativity, communication and persuasion, and entrepreneurial thought and action. These characteristics may be better described as attitudes, behaviours, and motivations rather than technical content and industry remains strong in its call for improvements in this area. Perhaps the reason is that in the past 50 years, engineering education has evolved more toward applied science and further away from the design and test methodology that remains the heart of the practice of engineering. In this sense, real engineering has less to do with a body of knowledge than it does with an iterative design process.

Soon after Olin College was chartered, the Foundation engaged an architectural design firm to begin developing a campus master plan. When I was hired in 1999 as the first employee, Olin College consisted of five people (the four Directors of the Olin Foundation and me) and was still just an idea, not a place. By early 2000, 75 acres of land was purchased from Babson College in the Boston suburb of Needham. Ground was broken on the construction of the campus in May 2000, and the first faculty were hired in fall 2000. This small group of founding faculty was supplemented in fall 2001 by a group of 30 young high school graduates (Olin Partners) who joined the faculty in a process of inventing and testing various dimensions to the curriculum. (These students became part of the entering freshman class the following year, and spent a total of 5 years in obtaining their B.S. degree at Olin.) During the Olin Partner Year the College was able to perform many pedagogical experiments that are not feasible in a program that is teaching regular courses for credit. The process of developing the Olin learning model (or curriculum) took two years, and involved a systematic series of steps involving discovery of best practices, invention of a fresh approach, development of new teaching methods and materials, and test/iteration with the Olin Partners.

The first classes were taught in fall 2002, when the total student population was about 75, all of whom were freshmen. The following year, another 75 freshmen were added so that the total enrolment grew to about 150. Courses taught in 2003-04 consisted of both freshmen and sophomore level classes. The next year another 75 freshmen were added to reach a total enrolment of about 225, and the courses involved freshman, sophomore, and junior classes. The first students to complete the program received their B.S. degrees in 2006. Olin offers B.S. degrees in three fields: Electrical and Computer Engineering, Mechanical Engineering, and Engineering (a more general option that provides a bit more flexibility for students to tailor the degree program to their individual interests).

Olin's learning model is unusual in several respects. For example, admission to Olin requires a weekend of on-campus interviews involving teamwork. Olin's student body is nearly gender-balanced, which is very rare in engineering. Olin's program requires a core sequence of courses in design through several years, and every student is involved at least one team design project in nearly every semester. Every Olin student must start and run a business to graduate. Olin requires all students to complete a year-long senior design project sponsored by industry.[4] Olin requires all students to *"stand and deliver"* in front of an audience including professional engineers at the end of every semester.[5] Olin students may cross enrol without charge at neighbouring Babson College[6], Wellesley College, or Brandeis University. Olin's program enables students to study abroad for a semester and still graduate within four years[7]. Olin's graduates have exceptional career opportunities. Princeton Review reports that Olin students rank #3 in the U.S.in the category "Students Study the Most," even though Olin students also rank #8 in the U.S. in the area of "Happiest Students." In addition, Olin Professors rank #4 in the U.S. in the category "Professors Get High Marks," and Olin ranks #5 in the U.S. for "Best Classroom Experience." Even though the total enrolment at Olin remains at only 350, last spring 16 Olin graduates received the prestigious NSF Graduate Research Fellowship to study science or engineering at any of the nation's top graduate programs. Olin was recently recognized as Top Producer of Fulbright Scholarship winners. Between 30 and 40% of Olin's graduates have gone on to graduate education, mostly in engineering and the sciences (but also in medicine, law, and business). Twenty-two percent of those students who go on to pursue graduate study do so at one of three universities: Harvard, Stanford, or MIT.

Perhaps the most important measure of change that has resulted from the Olin learning model is provided by the nationally-normalised scores from the National Survey on Student Engagement, administered by Indiana University. This metric is based on surveys of more than 600,000 students from throughout North America at more than 500 universities, focusing on the kinds of activities and the amount of time spent on each that characterize the learning program on each campus. Olin College is placed well above the 90% percentile in each of the five major areas covered by this measurement: (1) level of academic challenge; (2) active and collaborative learning; (3) student-faculty interaction; (4) enriching educational experiences; and (5) supportive campus environment. These five major areas have been shown to correlate well with durable educational achievement[8].

Olin College also has a mission to share what it has learned in the area of educational innovation with other universities and encourage change and improvement in the mainstream of engineering education. As a result, we have a partnership with several other schools, including the University of Illinois at Urbana-Champaign. Olin has been visited by about 100 colleges and universities from around the world in the last two years, and has established a popular Summer Institute on curricular innovation that attracts many faculty members from around the world. More information on these summer workshops is available at the website for the Olin College Initiative for Innovation in Engineering Education (I2E2): http://i2e2.olin.edu

A more complete explanation of the rationale behind the Olin learning model and its relation to the engineering challenges and educational advances of the 21st century are provided in a slightly longer paper presented last year[9].

References

1. Engineering, Olin MA 02492 (richard.miller@olin.edu)

2. The F.W. Olin Foundation was dissolved after creating Olin College, and no longer exists.

3. National Way, Needham, President, Professor of Mechanical Engineering (and first employee), Franklin W. Olin College of Academy of Engineering (2005) Educating the Engineer of 2020: Adapting Engineering Education to the New Century, Washington, DC: National Academies Press; National Academy of Engineering (2004) The Engineer of 2020: Visions of Engineering in the New Century, Washington Engineering, Olin MA 02492 (richard.miller@olin.edu)

4. Each sponsoring company must provide $50,000 in program support for a team of 4 – 6 students

for a 2-semester project. The company supplies the project goals and description and retains any new intellectual property generated by the students. Students often sign non-disclosure agreements with the sponsoring company, and patents are sometimes developed which include the stu-dents as co-inventors.

5. Students, either alone or in small groups, must either make a 30-minute presentation or provide a professional-grade poster presentation to an audience consisting of the entire faculty, students, and staff, and an additional 100 visitors from local industry and other universities, at the end of each semester. By the time each student graduates, s/he has done this 8 times. Olin is located adjacent to Babson College in order to encourage Olin students to take advantage of Babson's strong emphasis on Entrepre-neurship. Our goal is to "infect Olin students with entrepreneurial disease" while mixing the DNA of engineering and entrepreneurship. Babson College has been ranked #1 in the U.S. in Entrepreneurship by U.S. News & World Report and other national media for many years.

6. Between 25 and 30% of Olin juniors take advantage of the opportunity to study abroad each year, a number which far exceeds the U.S. national average for students majoring in engineering.

7. Olin is located adjacent to Babson College in order to encourage Olin students to take advantage of Babson's strong emphasis on Entrepreneurship. Our goal is to "infect Olin students with entrepreneurial disease" while mixing the DNA of engineering and entrepreneurship. Babson College has been ranked #1 in the U.S. in Entrepreneurship by U.S. News & World Report and other national media for many years. Babson has also developed a special M.S. in Technology Entrepreneurship degree that Olin students may complete within one semester after completing the B.S. at Olin.

8. Between 25 and 30% of Olin juniors take advantage of the opportunity to study abroad each year, a number which exceeds the U.S. national average for students majoring in engineering.

9. Miller, R.K., *"From the Ground Up: Rethinking Engineering Education for the 21st Century,"* Proceedings, Symposium on Engineering and Liberal Education, Union College, Schenectady, NY, June 4-5, 2010, pp. 3-20. (Available online at: http://www.union.edu/integration/2010_docs/2010-ele-proceedings.pdf)

4.6.4 Aalborg University

Aalborg University has been a leader in using Problem Based Learning (PBL) [49] as the core of its engineering education programs since 1975. It has deliberately chosen this strategy to transform its program and the outcomes have been carefully researched and prove the merit of its approach. Its programs devote up to 50% of the available time to PBL and have demonstrated the importance of enhancing student motivation and learning effectiveness through the student–centred learning that is created by PBL. The projects are team based, of variable scale, are multi-disciplinary, tend to be close to professional reality and act to integrate the students learning. The academic staff act as advisors, but the projects are directed by the students. The projects may be accompanied by relevant support courses. The students are largely self-directed, but their management of the project, their time and the available resources are each considered to be important. The Contributed Panel authored by Professor Anette Kolmos, the UNESCO Chair in PBL in Engineering Education and the former President of the European Society for Engineering Education (SEFI), addresses the factors which together act to prevent the implementation of change. Her panel is also highly pertinent to Section 10 of this Publication where it is presented.

4.6.5 CDIO

The CDIO Initiative [16] aims to improve undergraduate engineering education in participating institutions. It commenced in 2000 with the collaboration of four Swedish universities (The Royal Institute of Technology, Chalmers U of T, Goteborg and Linkoping) together with Massachusetts Institute of Technology. The project vision was to provide students with an education that stresses fundamentals set in the context of the engineering roles of Conceiving-Designing-Implementing-Operating (CDIO) real-world systems and products [50]. The project's primary goals are to educate students to: master a deep working knowledge of technical fundamentals, lead in the creation and operation of new products and systems, and to understand the importance and strategic value of their future research work. Design-build-test projects are a major feature of the program. The program incorporates a whole of lifecycle approach to engineering and places emphasis upon the responsible consideration of environmental issues [51].

In 2004 the CDIO Initiative defined the 12 standards that describe CDIO programs [16]. They involve:

1. "Adoption of the principle that product and system lifecycle development and deployment (CDIO) are the context for engineering education.

2. Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders.

3. A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.

4. An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills.

5. A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level.

6. Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning.

7. Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills.

8. Teaching and learning based on active experiential learning methods.

9. Actions that enhance faculty competence in personal, interpersonal, and system building skills.

10. Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.

11. Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge.

12. A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement."

Of these standards 1, 2, 3, 5, 7, 9, and 11 are considered to be essential for recognition of a program as a CDIO program. The other 5 supplementary standards are advisable as they reflect best practice in engineering education. The CDIO program represents a very significant transformation of engineering education as it takes a total system approach to the issue of developing the future engineers. It is a structure suitable for any discipline within engineering. The development of the student's capabilities is compatible with the broad range of Washington Accord attributes. Its emphasis upon experiential student learning to achieve the development of personal, interpersonal and professional skills is exemplary. It also emphasises the importance of staff ensuring co-ordination of content across the components of the course and emphasises the reality of the need for staff development to achieve the programs objectives. The design-build projects can provide motivation early in the course and highly appropriate experience for advanced students. The need for different student work-spaces and facilities is also recognised. Importantly the assessment is required to be matched to the program goals and quality management is achieved through regular evaluation with feedback to all participants.

These 12 standards comprise an open architecture that universities are invited to adopt. Currently more than 50 universities have decided to adopt the CDIO model. This is an encouraging sign that indicates a willingness to recognise the need for transformation in some institutions. The 50 institutions have a very high Nordic representation, but also a good spread through North America, Europe, Australia and Latin America. While it is understood that implementation of each of the 12 standards will take a period of time in participating universities, and that consequently a commitment to the 7 essential standards is a reasonable initial commitment for participating universities, it is considered that the transformation to be achieved by adoption of the CDIO system requires a commitment to the implementation of all of the 12 standards.

4.6.6 Higher Education Academy

The United Kingdom has provided a system wide approach to facilitating the enhancement of the effectiveness of learning through the establishment of this Academy. It has created Subject Centres in 24 disciplines in various universities. The Engineering Subject Centre which was established at Loughborough University has a mission to deliver subject based support to promote quality learning and teaching. It does this "by stimulating the sharing of good practice and innovation, thereby helping engineering academics to contribute to the best possible learning experience for their students." [52]

Its website provides many useful materials to assist engineering educators. The work of the Centre is explained in greater detail in the Contributed Panel authored by Professor John Dickens. Unfortunately, recent government austerity measures in the UK mean that the funding of the Subject Centres has been discontinued.

Contributed Panel No. 7:

Delivering Support for Learning & Teaching in Engineering

Professor John Dickens

Director of the HEA Engineering Subject Centre 2000-2011, Loughborough University.
Director of the Engineering Centre for Excellence in Teaching and Learning 2005-2010.

I have taught students of Civil Engineering at Loughborough University since 1981 and been the Director of centres providing support for the development of learning & teaching in engineering both within the university and nationally across the UK since 1999. There have been many changes over the years and whilst I believe that teaching quality has improved it is my view that today's academics are under more pressure to deliver high quality teaching than their predecessors. In the UK the introduction of tuition fees, and their subsequent increase, has increased student expectations. The National Student Survey has been a measure of student satisfaction used to rank both universities and individual disciplines and has been closely scrutinised by university management. The increase in participation rates has led to a more diverse student cohort and employers have increasing questioned whether graduates are fit for purpose. The pressure to deliver high quality teaching has never been higher.

The UK was, I believe, the first to create a national network for discipline based support through its 24 Subject Centres. Other countries have subsequently adopted this strategy to some extent including Australia with their Discipline Scholars and most recently Germany with their TeachING & LearnING centre run by the universities of Aachen, Bochum and Dortmund (http://www.teaching-learning.eu). The Higher Education Academy (HEA) in the UK (http://www.heacademy.ac.uk) , as part of a major restructuring due to some extent to funding cuts, is to close its subject centres in 2011. The ongoing strategy of the HEA is to maintain discipline support but run through its headquarters rather than the subject centre network which was distributed among some 20 UK universities.

The Engineering Subject Centre's mission changed slightly over the years but was to provide the best possible higher education learning experience for all students, and to contribute to the long-term health of the engineering profession. This was achieved through four main aims:

- Sharing effective practice – brokerage
- Championing teaching
- Promoting engineering education research
- Informing and influencing policy.

In reflecting on how effective the centre has been I will draw on a few examples in each of these areas. Further details on the work of the centre can be found at http://www.engsc.ac.uk

The centre has been successful in building up a community of practice which encouraged individuals to learn from each other by sharing practice. This was achieved through a variety of mechanisms but at the core a comprehensive website and resource database which became a 'one stop shop' for anyone seeking information on learning & teaching in engineering. Brokerage is perhaps the word that best describes the process of drawing academics into the centres activities to share their practice through events, publications or the website.

Commissioned publications of specific topics written by engineers have proved to be very popular; topics have included Design Teaching, Assessment & Feedback and Learning and Teaching Theories. The take up of these resources confirmed the centre's belief that engineers relate to material written in the context of the discipline even though much of the content is generic.

Mini-project funding has proved to be a very successful strategy where individuals bid for a small amount of funding (£3500) for research or development projects to deliver defined outputs that are relevant for others. An essential part of the process is the support provided by centre staff throughout the project to ensure delivery and that underpinning evaluation is built in. The mini-project scheme delivers good resources to the community whilst giving the grant recipient some national recognition for their teaching practice. The centre has been able to make resources available over an extended period which overcame a problem that existed when resources developed in short-term funded projects became unavailable when funding ceased and the project team broke up.

Championing teaching is of great importance in achieving and maintaining transformation and innovation in Engineering Education. Developing new methods of teaching & learning requires time and commitment from individuals and if this is to be nurtured then it is essential that appropriate reward and recognition systems are in place. When the centre first started it was not uncommon to hear academics lament that they wanted to adopt new methods for their teaching but could not devote the time needed as it would have a negative impact on their career prospects. Over the last decade UK universities have increasingly included teaching excellence in promotion criteria and this identified the need for external evidence to demonstrate its achievement. The centre has been able to contribute to this evidence through teaching awards, the award of project funding, providing publication outlets or work as an Associate. There are a number of individuals who have achieved promotion to senior levels whose work with the centre has been a contributory factor in providing external evidence of esteem.

At the start of the centre's work there was little activity in engineering education research and it became part of the centre's strategy to build capacity in this area to underpin an evidence based approach to the development of teaching and learning. The Engineering Education Journal (http://www.engsc.ac.uk/engineering-education-journal) was launched in 2005 in response to the need to provide a publication outlet for academics working in the area. The Centres for Excellence in Teaching and Learning (CETL) programme in the UK (2005-2010) also had pedagogic research as a core activity and the engineering CETL at Loughborough (http://www.engcetl.ac.uk/) had a programme of research including PhD projects. The two centres collaborated to produce an Introduction to Pedagogic Research toolkit for engineers (http://www.engsc.ac.uk/downloads/ped-r-toolkit.pdf) and ran a number of workshops that proved very popular with high attendances. Activity in this area has grown and the biennial engineering education conference (EE2010) which has run in it's present form since 2004 has continued to attract an increasing number of research based papers in engineering education. Support for engineering education research is to continue in the UK with the publication of future issues of the journal and the running of EE2012 by the Engineering Education Centre at Loughborough with funding from the HEA.

Informing and Influencing policy is a key activity for any centre or group providing discipline support in Engineering. A centre needs not only to work with the academics delivering the teaching but also the various bodies providing the strategic policy environment in which they operate. In the UK this not only includes government bodies such as funding councils and the Quality Assurance Agency (QAA) but the professional bodies like the Engineering Council and the Royal Academy of Engineering (RAE) and the subject associations like the Engineering Professors Council. An early example in the benefits in working closely with these organisations was the role the centre was able to play in demonstrating that the academic community wanted AA to adopt the Engineering Council's Output Standards (UKSPEC) (http://www.engc.org.uk/professional-qualifications/standards/uk-spec) as the subject benchmark statement. This meant that academics only had to work to a single standard rather than having to meet similar but different output standards for university quality assurance (QAA benchmark) and external accreditation (UKSPEC). A more recent example has been the Collaboration with the RAE on the Engineering Graduates for Industry Study (www.raeng.org.uk/egi).

The RAE was commissioned by government to lead on the development of 'experience-led' engineering degrees that met the recruitment needs of industry. The subject centre was commissioned to conduct the research and adopted a case study approach drawing 15 exemplars from 6 universities (www.engsc.ac.uk/graduates-for-industry/). The subject centre was in a unique position of having the detailed knowledge of who was doing what in which universities and working with those influencing policy.There has been good progress in engineering education in the last decade. There is more project/problem based learning in the curriculum, more embedment of technology in the learning process, a greater openness in sharing practice and adopting the practice of others and in my view better reward and recognition for teaching.

4.6.7 Engineering Ethics

The Carnegie Report [32] expressed its concern that the consideration of engineering ethics is inadequate or non-existent in most engineering education programs. They also indicated that any consideration given to the topic is often outsourced to non-engineering faculty with less than adequate results. A number of Universities (RMIT University, Auckland University of Technology and Hochschule Wismar University) have co-operated to provide a concentrated short course in engineering ethics. In the Contributed Panel authored by Professor Buckeridge an interesting way of assisting students to develop an understanding of this issue is described and material to assist academics seeking to implement courses in this field can be accessed on their website.

Contributed Panel No. 8:

The Evolution of Ethics Education as an Integral Part of the Undergraduate Engineering Curriculum

Professor John St J S Buckeridge

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Setting the scene

The imperative of the 1989 Washington Accord, that engineering be carried out *responsibly and ethically and be environmentally sound and sustainable,* arose because of widespread public concern about environmental degradation, and the perception, rightly or wrongly, that engineers had played a significant part in this. Unless the above criteria are met, engineering programs will not be accredited; thus the driver for the formal inculcation of ethics within the undergraduate engineering education began.

Nonetheless, it is infinitely better to teach a course because it is intrinsically valuable, rather than because it is mandatory. Engineering ethics fits the former well. Indeed, it is much more than avoiding environmental degradation; it is all about ensuring sustainable practice – beginning with competent engineering, undertaken in a sound economic manner and which benefits the community it serves. This complements the caveat "to do no harm" – either to the environment or to wider society (Buckeridge, 2011). Good ethical practice attains these best outcomes when engineers possess moral autonomy – i.e. when they have the ability to independently evaluate an ethical conundrum on the basis of moral concern (Martin & Schinzinger, 2005).

In pursuit of best practice

Courses in engineering schools are generally taught as a lecture, followed as appropriate, with a tutorial and/or a laboratory class. On some occasions, there are site visits. Courses run a full semester. However, rather than have a separate course for ethics, it was initially considered expedient to deliver any "ethical component" within the fabric of existing courses – i.e. to contextualize it. To some degree this was happening of course, especially in core courses that deal with professional practice. Nevertheless, there was a broad unwillingness to inculcate ethical theory within standard class lectures. Reasons for this are various, including exactly where it could be done, in for example very technical subjects such as structural mechanics; however the greatest obstacle was perhaps pedagogic – and this followed an appreciation that ethical frameworks are best achieved through an understanding of the moral theory that underlies these frameworks. However, most engineering faculty members are unwilling, or uncomfortable, with teaching moral theory.

An alternative, to offer a separate course on ethics, and have it taught by somebody from the humanities has appeal and can certainly fill any void in delivery. But earlier experimentation along these lines, with subjects like communication skills, often failed due to misconceptions by those in the humanities about science and engineering communication style, thinking and process. Although this may simply be a reflection of the type of lecturers who were "volunteered" to teach engineering undergraduates, we should be mindful that there are at least two cultures – the arts and science/engineering (and perhaps also commerce) which have distinctly different ways through which they view their worlds (Buckeridge, 2008).

The most successful approach to deliver an ethics course at RMIT University was as a short course, in which students were immersed in moral theory, ethical constructs, and case studies for a week. In most cases, we have been

Table 1: Development of the Concept. A "block course" is presented over a short period of time, generally one week, wherein students are taught, assessed and marks allocated. The developmental phases shown above were trialled at Auckland University of Technology (New Zealand), Hochschule Wismar University of Applied Sciences, Technology, Business and Design (Germany) and RMIT University (Australia). The same lecturer taught all the courses and this alone precluded any full semester delivery, although it did allow invaluable international benchmarking. In conjunction with the above three universities, the course was also given exposure to a wider global community, being taught in China, Fiji, Sweden, the United Kingdom and the United States.

Activity	Options	Comments	Outcome
Timing of Delivery	Spread throughout the entire program.	Students and staff find it difficult to develop enthusiasm for the topic.	Low uptake of concepts. Trial closed.
	As a block course in first year.	Concerns about whether students know insufficient about the discipline to appreciate subtleties of moral conundrums.	Student response variable, depending upon background. Trial closed.
	As a block course in final year.	Students primarily involved in projects, providing greater flexibility in the timetable for a week-long ethics course.	Adopted. Students able to contextualize ethical problems in their discipline. Option adopted.
The learning environment	Standard lecture followed by tutorials.	The nature of the topic and the need to encourage student engagement made this option unpalatable.	Not sustained.
	Focus on case studies. Presentation of an ethical concept, followed by group-work assessment of the issues raised.	This option provided students with the opportunity to discuss issues in a small group first, and then give *group* feedback, minimizing potential for any demeaning comments from others.	Adopted.
Assessment	Formal tests followed by end of course examination.	With large classes, there may be insufficient time to mark all tests and assignments before the end of the course.	Not trialled.
	Peer assessment of group projects during the course with end of course examination.	Relying solely upon peer assessment has sometimes raised student concerns about fairness.	Adopted. Grading of groups undertaken 50:50 by peers and faculty (eliminating a liklihood of bias).

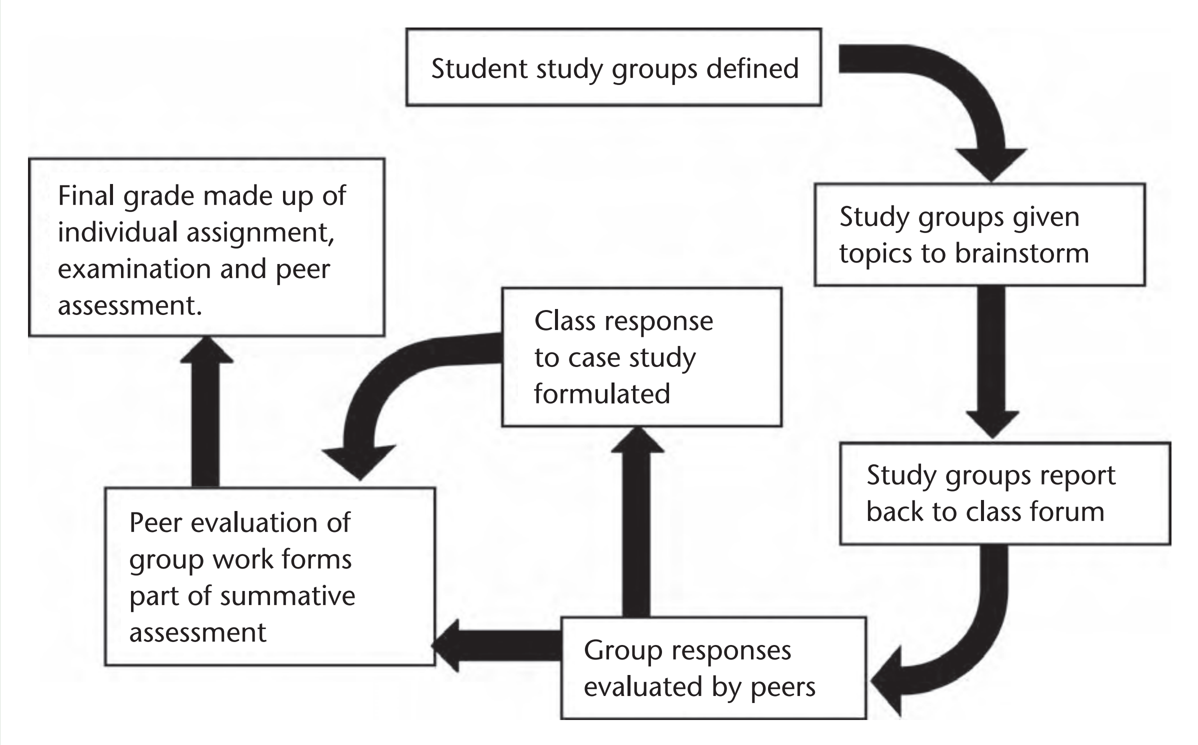

Figure 1: The learning environment.

able to ensure that at that time, they had no other classes that would detract from their learning environment (Table 1). This model has been assessed annually by students, and is consistently one of the most popular courses taught in the school (Buckeridge & Grünwald, 2010).

A course that extends only over a week does not fit the format required at some institutions. At RMIT we had to combine Engineering Ethics with another topic (in this case Engineering Law) to conform to program requirements. However, both law and ethics were taught and examined independently, although the marks were combined for the final grade.

The learning environment

Non-technical subjects, especially if they fall outside an otherwise mathematically oriented curriculum, are often perceived as having low priority by engineering students. The best model through which to overcome lack of student engagement was found to incorporate group work. The lecturer, generally using visual aides, introduces each case study. Any technical questions and ethical issues raised are then discussed separately by each student group (Figure 1). After discussion, a student, selected at random from each group, reports back to the class forum. Debate, often vigorous, determines the best response, hopefully with a class resolution agreed by the end of the session.

On the final day of the course, each group presents their solution to the ethical conundrum that they had been given on the first morning of the course. They have had four days to deliberate upon their response – and they must now give their findings as a presentation, at which they are cross-examined by their peers and lecturers. Each presentation is graded. Initially it was planned to have this part of the course fully peer assessed; however a deputation from students, who were concerned about potential bias of their peers, led to the modification whereby grading is undertaken by both peers and faculty (i.e. 50:50), ensuring no skewing of the marks.

Throughout the course, the learning environment is primarily structured around case studies; this suits the topic well and in small study groups allows wide discussion about what is best practice. It is also the most effective manner to ensure student engagement (Martin & Schinzinger, 2005; Dowling et al. 2010; Buckeridge, 2011).

Opportunities with new technologies

Advances in information technology provide wonderful opportunities to enhance the learning environment, and this is no more exemplified than in mathematical disciplines such as engineering, where there are limits to solutions in good engineering.

In general, these limits or tolerances are embodied in compliance codes. Not surprisingly, some excellent self-assessment software packages have been developed that students can use in, for example, structural analysis and design. However the development of similar software packages for problems that include unresolved ethical issues are very much more complex. The solution to any ethical conundrum is often predicated on the environment, especially the social or environmental setting, e.g. concerns about biodiversity will dominate in most natural environments but are unlikely to be important in buildings other than those in zoological parks.

Figure 2 is a schematic representation of what underlies a web-learn package for self-assessment that was developed at RMIT University. The boxes that have a bold border show the path of action that is most appropriate. There are of course other options that the user may choose, and if this is done, no mark is given, although the reasons why this choice is not the best are given.

Students using this web-learn package are expected to form networking groups to discuss each case study; the exchange of ideas, and perspectives further enriching the learning experience. As there is no mechanism to ensure the identity of the user, we have no intention to use this for anything other than formative assessment. The package is accompanied by an overview of the three primary moral codes that underpin ethics – utilitarian, deontologic and virtue ethics, and is currently available free-of charge.

It is planned to provide further case studies, from different disciplines, to give the site appeal outside engineering. When this happens, and networking eventuates, there will be excellent opportunities to exchange a wide plethora of views. One concern that arises is the integrity of the site; if users see this site as an opportunity for abuse or inappropriate behavior, it will need to be withdrawn from the open domain. The future of every site of this nature involves the vigilance of monitors… and this has the potential to be very time consuming.

Conclusions

As there is wide acceptance that adoption of a moral framework is achieved well before students arrive at university to study engineering, the question about whether students can learn to be more moral at age 20 is rather intriguing. Nonetheless, it is contended here that a useful learning environment can be provided at universities, where the opportunity exists to discuss and to debate different moral perspectives. This course is run in a non-confrontational environment where different perspectives on what is ethical behaviour arise. The course also provides students with the opportunity to appreciate how and why codes of ethics have been developed, and why, in the 21st Century, they are still evolving.

Finally, and most importantly, this type of course on engineering ethics gives participants the ability to develop their own moral autonomy, wherein their confidence and independence to evaluate and resolve any ethical conundrum is enhanced.

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A young graduate is employed in the Cape Town branch of a large pharmaceutical company. Through her manager, instructions are received from Head Office in Los Angeles to undertake a development project. The project is a large task that will take three years to complete. The work is especially welcome because the branch has been under threat of closure as a result of cost cutting and a failure to attract sufficient work.

When going through the correspondence and briefing material, the graduate finds a confidential file that has been enclosed by accident. It shows that the work to be undertaken is a waste of shareholder's money, but that this is being covered up to protect the branch manager and a local politician, whose seat is marginal. Reference is made in the file to a restricted report from a highly respected consultant who advises strongly against the proposed project on environmental grounds.

The graduate photocopies the file, tells her manager and they both go to their branch manager. After having handed over the original file, they are told by the branch manager to "forget you ever saw it!" There is also a threat that should this become public, some employees could lose their jobs. Closure of the branch office is a possibility, at a time when similar work opportunities in the region are unlikely.

Determine on ethical grounds, what is the most appropriate action for the graduate.

The graduate rings the local television station and offers the environmental reporter there a "scoop".	The graduate contacts her professional body (she is a graduate member), and seeks guidance of what she should do next.	The graduate does nothing, believing that it is none of her business.
This too is a deontological response. Here the graduate is an *internal* whistle-blower, although it is unlikely that she will remain so. Even if well intentioned, this may alienate some parties, making the whistle-blower less employable, especially if the person has not followed "due process".	This is the best path to follow if internal resolution fails. Professional bodies strive to resolve ethical issues in-house as it reflects badly on the profession if they become public. The profession may not have a section that deals only with ethics, but they will have experienced mentors.	This comes close to the transgression known in legal terms as "willful blindness". This applies when one could have been aware of an issue that may have significant negative effects, but when one chooses to ignore these. In this situation, even the medium term outcomes are likely to be bad.

The ethical constructs on which this decision is based are deontologic (the driving motive is duty – to the wider community and the profession) and virtue (where there is demonstration of honesty, and an acceptance that there are limits to one's knowledge).

Figure 3: Web-learn self-assessment of an ethical conundrum. The above example is one of a series of case studies that are now on-line. It begins with an ethical dilemma and provides the user with the choice of three alternative actions. They must select one. Their selection is then locked and the comments in the shaded box immediately below their choice appear. If it is the correct one, they are "given a star". If they are wrong, they get no star, and nor can they reselect. However they are still able to review the rationale behind the other two choices by clicking on these options. If they wish to return to the beginning of the test, they may start it again, hopefully making the correct choices as they move through the example.

4.7 The Enhancement of Student Motivation

The educational program exists for students and they will not be successful if they are not committed and motivated. Consequently the development of a high level of interest, commitment and motivation must have a major focus in any transformation process. Low levels of motivation are evidenced in the high failure rate that occurs in many engineering education programs with most of this being in the first year and the dominant determining factor usually being the mathematics component of the program. The overall failure rate in year one of engineering courses often exceeds 25% and can approach 40%.

The experience of the student determines their motivation. There are many factors that can cause the student experience to be unsatisfactory and the student's motivation to wane. They include:

- The topics to be studied are too theoretical,
- There are too many concepts packed into a subject,
- An insight into what engineering is about is not developed,
- The mathematics component is too difficult and not well matched to the students previous mathematics experience,
- Large lectures may provide an ineffective learning environment,
- Students have limited access to academic staff when they are a part of a big group,
- Students may feel isolated without close friends and effective communication networks.

To enhance completion rates these issues must be addressed. The development of high levels of motivation must become a key objective of the first year of programs. It has been suggested that the following actions are desirable [53] to achieve good motivation:

- Provide pre-entry guidance and induction,
- Provide a stimulating learning environment,
- Utilise of interactive learning experiences such as laboratory and project work,
- Provide the opportunity to work in teams,
- Provide personal staff interaction with the students in this transition period,
- Review the approach to assessment (Section 6.6),
- Consider how mathematics will be presented and linked to engineering (Section 6.3),
- Undertake practical activities that provide insight into the nature of engineering,
- Facilitate student discussions,
- Invite presentations by engineers from industry,
- Undertake visits to engineering project sites,
- Use of technology to enhance the learning experience,
- Utilise of current issues (e.g. sustainability and ethical issues associated with major projects) as topics for discussion,
- Give formative feedback to each individual on their development,
- Introduce insight into some of the various disciplines of engineering,
- Provide an opportunity for successfully solving an engineering problem, completing an engineering project or creating a working model,
- Provide students with the opportunity to

influence their learning plan and learning experiences.

The first year of the engineering education program has a major impact on student retention. Many engineering education programs have a common first year curriculum for all students regardless of the discipline that they wish to pursue, e.g. [54]. Such programs often include an introduction to engineering and contain a strong mathematics and science component with varying effectiveness in its relationship to the engineering objectives of the program. There may be some provision for streaming of commencing students on the basis of their demonstrated competency in mathematics, but this does not entirely address the fact that there will be a large diversity in their abilities, understanding and prior experiences in mathematics. For the majority of students the mathematics and science components of the program are not highly motivating. While foundation knowledge in these fields is acknowledged as important, ways of facilitating their connection to the engineering program's objectives need to be identified to enable motivation to be maximised at the commencement of their program.

The first year should be orienting the students to engineering practice. The learning objectives should primarily relate to the development of their professional capabilities and not to the development of the science and mathematics tools. The latter should be developed as a corollary of the engineering requirements and as a result of the need to explore an engineering situation. Engineering projects and engineering experiences should be utilised as the vehicle to provide focus and motivation for the students. This provides the context of the program and the motivation to learn what is necessary to reach the goal of professional practice.

Common first year programs are often used because they are cost efficient, but they are provided for a diverse group of individuals. Typically the objective is the development of the fundamental technical foundation that is required for a number of engineering programs. The suggested alternative approach is to use the first year to commence the exploration of engineering issues, concepts and challenges through the consideration of engineering projects. From the student's perspective the program can be diverse with them working on allocated projects. Acting as if they are part of an engineering office, working in teams, exploring information sources, understanding the various issues, assessing and comparing alternative solutions, preparing and presenting reports, could be far more exciting, motivating and successful in demonstrating what engineering is about, while commencing the development of the attributes that an engineering graduate requires. With such an approach, the necessity to understand the science, mathematics and engineering principles will be created and can be utilised to explore topics as required, rather than being an enforced and seemingly unrelated requirement. Such an approach can enhance motivation, facilitate the student's development as engineers and increase their likelihood of success. It also develops an engineering approach to problem solving and the practice of independent learning within a team structure. It may even be fun for them to be involved!

It is now possible to identify that:

The third step towards Transformation is the design and implementation of the first year of the engineering education program to maximise student motivation.

The transformation of engineering education programs to become more interesting, more motivating and more relevant to professional practice, will not only directly address the important issue of the poor retention rate of students, but it is also essential to improve the participation rate. The image of engineering being a difficult and boring program is rapidly transmitted through the student community and acts to deter the less committed students. While the number of students undertaking university education is increasing quite rapidly in most countries, the number of students studying engineering is relatively static in most developed countries resulting in a continual decrease in the percentage of total university students choosing to enrol in engineering.

The solution lies in making the engineering programs more interesting and increasing the success rate of students so that the message conveyed to potential students is that it is an important and worthwhile career pathway for women and men. Coupled with an improvement in the understanding of what engineers do and how they have essential roles and responsibilities in contributing to the well-being of their society by the application of technology, engineering education programs can be made both more attractive and more effective.

The need to be gender-inclusive applies to the whole curriculum and not just the first year. The issue is most helpfully discussed in the Contributed Panel authored by Ayre, Mills and Gill. They note that inclusive curricular improve the retention rate of all students and not just female students. Inclusivity which extends to also include international students, students from disadvantaged backgrounds and in fact all students, without discrimination is a responsibility of all staff which can only result in the program effectiveness being enhanced.

The image of engineering is less attractive for students than it could or should be. Students are motivated by being able to improve society by environmentally responsible actions, by assisting development in the less developed world and by improving facilities and creating new ways of assisting to solve problems in their community. This clear message of what engineering is about is not often conveyed explicitly to potential students. Employers and professional associations have a role to play in assisting universities to diversify and enlarge the student intake by demonstrating that an engineering career can be attractive to female students and students from disadvantaged backgrounds. Improving the community's understanding of the role of engineers is a key component of this responsibility. Information for girls considering an engineering career is available [55] and could be used more effectively.

An excellent report [56] of research conducted into the factors enabling engineering students to be successful has been funded by NSF and undertaken by the Centre for the Advancement of Engineering Education. It outlines six key topics that should be carefully considered. They are:

- Welcoming students into engineering
- Understanding and connecting with today's learners
- Helping students to become engineers
- Developing the whole learner
- Positioning students for professional success
- Welcoming students into the work world.

They pose a set of challenging questions for the consideration of each engineering education campus that is committed to improving the success rate of its students. They relate to the motivation of students, how they are treated, curriculum design, program relevance to their career activities and the design of learning experiences.

It will be seen from the diverse considerations that have been discussed that there is clear evidence of the need for transformation of engineering education and many groups have been contributing to the identification of the principles that must be followed and solutions that can be utilised in implementing solutions. Generating the will and the tools to enact the transformation are the next steps to be considered.

Contributed Panel No. 9:

A Gender-Inclusive Engineering Curriculum

Dr Mary E. Ayre, Professor Julie E. Mills and Professor Judith Gill

The University of South Australia

In most countries across the world women constitute less than 25% of engineering students and less than 16% of the professional engineering workforce. In the major English-speaking regions: North America, the British Isles and Australasia, the figures are even worse, with less than 19% of engineering students and less than 12% of professional engineers being female, and in most of these countries these proportions are currently falling. Other countries are more successful in attracting women to engineering. In some Middle Eastern and East European countries more than 25% of professional engineers are women (Mills, Ayre & Gill, 2010a) and in Kuwait, nearly 50% (Kanga, 2009).

The very low female representation in the profession in some countries is clearly not due to women lacking the necessary abilities to become an engineer, but relates to a range of reasons such as the lack of women studying required subjects at school to gain entry to the necessary engineering degree qualifications, the perception that engineering is a "male profession" and problems with retaining women in engineering study and professional practice. Increasing the number of women in engineering and others from minority cultural groups is an issue of social justice, as well as meeting the worldwide demand for more engineers to improve the quality of life everywhere. Greater diversity in the profession will ensure that a wider range of citizens play an active and informed part in the control and use of social assets.

Despite many programs and initiatives led by governments and other bodies to attract more girls and women to study engineering, in the countries with low female representation quoted above there has been very little improvement since the early 2000s (Mills et al, 2010a). Interest is now focusing on the traditional engineering curriculum as possibly being a significant impediment to engaging the interest and motivation of female students. A recent Australian report notes that "students and others have observed that engineering curricula (and physical science texts) tend to be crafted with over-use of masculine stereotypes and examples, such as automobiles, rockets and weapons" King (2008, p.72). A report from the US similarly observes that the engineering curriculum and culture are "at odds with the value systems of most young women and minorities, and ... probably at odds with many talented students of any race and gender" (NSF, 2005, p.36). These identifications of male bias in the curriculum have led to the view that the traditional engineering curriculum must become more 'inclusive' by taking into account the backgrounds, interests and views of all members of a diverse society.

What do we mean by an 'inclusive curriculum'?

An inclusive curriculum is one in which the subject content covered, the way in which it is taught, and the learning methods promoted take into account the variety of perspectives, attitudes and learning styles brought to the subject by students from different gender, cultural and social groups. Existing undergraduate engineering curricula tend to reflect male cognitive styles and interests. By emphasising recognition of the different values and perspectives of all students, including those of the dominant group, an inclusive curriculum should be both gender and culturally inclusive. Thus male students will not be disadvantaged, as international studies have clearly shown that inclusive curriculum strategies have improved student engagement, retention and success for all students, not just women (Mills et al, 2010a).

Gender inclusive curriculum in practice

In all of the ensuing discussion, 'curriculum' is defined as much more than a list of topics which have to be taught in a course or subject. It also includes the way in which a subject is developed, taught, managed and assessed, as well as the learning environment in general. For maximum impact an inclusive curriculum must be inclusive in all the components of a subject/module or the entire program. These components include: the assumptions made about the backgrounds, perspectives, values and expectations of all the students, the aims and objectives, the content, the teaching and learning methods, the learning environment, and the forms of assessment (Mills, Ayre & Gill, 2010b).

For example, it has been found that many students, particularly girls, who enrol in an engineering degree, have been encouraged to do so by teachers at school because they are good at mathematics and science, but they have little idea of what an engineer is or does. Others enrol because they have been impressed by the social impact of a big engineering scheme like providing water to a third world drought-prone area, rather than, as is often assumed, because they are passionately interested in the next generation of technical developments. Acknowledgement of these influences on a student's choices strongly suggests that there should be some information about the social benefits of engineering early on in an engineering degree program, rather than the sole emphasis being on basic mathematics and science which characterises many traditional engineering degrees. A classroom teacher can easily include alternative applications of a technology in a lecture or tutorial. More radically the course or module manager might consider including social and environmental issues, and career information in the course design. At a US university, first year retention improved to 100% when a small group project was introduced into the first year curriculum to explore or solve a societal issue or a community problem with a technical aspect (Isaacs and Tempel, 2001).

The learning environment is another critically important component of an inclusive curriculum. It has been found that women, and other groups who are in a minority in an engineering class are often uncomfortable because of disruptive behaviour by the dominant group, or racism, sexism or similar attitudes, or a cultural mismatch between the lecturer's expectations of a student's willingness to participate actively in the class. In a diverse class a lecturer needs to be particularly alert to any hint of sexism and racism, even if only meant jokingly, and act to prevent any recurrence immediately. More positively, if it is difficult to engage a group of students who are reluctant to participate in active learning (since learning is a social process), lecturers are encouraged to consult the students in a 'silent' group to help determine how to modify learning activities so that they feel more able to participate.

By addressing all the components of the curriculum with these sorts of questions, and looking for solutions, the curriculum can be made more inclusive. The questions to ask, together with many suggested solutions and other practical examples from real courses and programs are provided in the book *Gender in the Engineering Curriculum* (Mills et al, 2010a) and the summary document *Guidelines for the design of inclusive engineering education programs* (Mills et al, 2010b).

Embedding inclusive curriculum in practice

The previous examples show that a single lecturer can, on their own initiative, make parts of the curriculum more inclusive with consequent benefits to the minority social and cultural groups in the class. Many cases of improvements in student satisfaction, retention and success as a result of more inclusive curriculum practices are given in Mills et al (2010a). However, the student's experience of the broader engineering curriculum will only become more inclusive when other teaching staff and the departmental management also adopt more inclusive practices. This is a more challenging task.

The next step for the classroom lecturer after reviewing their own perspectives and expectations of a particular course or module, and making the classroom environment more inclusive of minority groups, is to address the formal parts of the curriculum such as the aims and objectives, and the content. Changing these components usually requires championing these new approaches through course review boards and similar bodies. Lecturers in this position may find that evidence of improved retention or success as a result of their own inclusive practice may be a strong persuader of others. Another useful 'persuasive' device might be to benchmark the perceptions of staff and students about the inclusivity of current practice (Jost, 2004). When this benchmarking exercise was undertaken in some engineering departments in Australia, the US and the UK it indicated that (not surprisingly) teaching staff generally perceived their teaching practices to be more inclusive than students did (Mills et al, 2008). Passing on such information would be useful for heads of department who may be seeking ways to increase the recruitment and retention of female students.

The strategies outlined above describe a 'bottom up' approach to the inclusive curriculum. Of course the whole process will be greatly assisted if there is also a 'top down' initiative from senior and departmental managers. This is also essential if a real and continuing curriculum transformation is to be achieved. *Gen-*

der Inclusive Engineering Education (Mills *et al,* 2010a) describes how Faculty Development exercises, Equity/diversity policies and practices, inter-department and cross-institution collaboration can all be harnessed to embed an inclusive culture in a university.

In summary our advice to fellow academics who are keen to improve the recruitment, participation and retention of women studying engineering is firstly to become more inclusive in your own teaching using ideas from the references cited here. When you see the improvements in participation, achievement and retention of both your female and male students, encourage your colleagues to experiment with inclusivity as well, providing them with the evidence and examples you can find in the literature cited here. You should then work with your colleagues to embed these inclusive principles and practice in your department. Some hints as to how you can do this are given here, and again further ideas together with successful case studies can be found in the literature cited. Good luck, and please write up your experiences to inspire and motivate colleagues coming after you in your own department and in other universities to also implement inclusive curricula.

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5. Approaches to the Transformation of Engineering Education

Transformation is a challenging concept. As technology has evolved and the nature and scale of engineering has changed, we are confronted by the fact that engineering education demands nothing less than transformation. It is no longer acceptable to defend the status quo by saying that we are doing our best, or that we are improving steadily. We must face the issue: we are living in a time when there has been a paradigm shift. It has radically changed technology, the nature and values of society, the attitudes of youth, the availability of information, the practice of engineering and the tools available for the processes of education. With a paradigm shift it is necessary to change our behaviour, our thinking, our planning and our approach. To do otherwise will not be sufficient or appropriate. A paradigm shift is difficult to handle; it is challenging. However it also provides opportunity. Significant benefits can result when the new environment is acknowledged and addressed. It is necessary to question everything associated with our current engineering education programs and to rethink how the desired outcomes can be most effectively delivered. A paradigm shift requires action [42], action requires leadership, and leadership requires courage and conviction [34].

The achievement of the transformation of engineering education will also demand incisive and informed innovation. The first three steps to be taken in achieving transformation have already been identified. The discussions in the preceding sections have also identified a number of additional engineering education program and process issues that should be addressed to facilitate the implementation of transformation. This section will consider these issues in sufficient detail to outline the contribution that they can each provide to the transformation process and why they are important. While each is important, they all interact to provide the opportunity for transformation of the engineering education system. Consequently they need to be considered holistically.

5.1 Program and Curriculum Modification

The program is the framework within which the graduate attributes are developed. The changes required are to emphasise the development of the functional capabilities of an engineer, as expressed in these graduate attributes, instead of the over-emphasis placed on technical knowledge. A sound foundation of broad engineering principles is required (based on an ability to use mathematical and scientific tools) that enables problems to be analysed, all the relevant factors and considerations to be identified, and the necessary information to be obtained, analysed and utilised, to facilitate the assessment of alternative solutions and the design and realisation of the most appropriate solution. A program and curriculum that enables the capacity to undertake this fundamental engineering process to be developed, by providing the opportunity to explore, practice, obtain confidence and develop the ability to implement, is the objective.

This will require a broad base of technical principles and knowledge with a deeper understanding in some chosen field of specialisation. The development of specialist knowledge is what universities usually prefer to emphasise and what the staff find most interesting and enjoyable as it relates to their research interest. It is also a necessary and useful experience for students to demonstrate that they can approach the forefront of a particular topic. However current programs typically include too much specific specialised detail at the expense of developing the general attributes essential to be an engineer. It is only after they have commenced their engineering employment that the particular areas in which they need in-depth technical knowledge will become apparent. Universities could offer these technical concentration electives in post-graduate programs as part of the requirement for professional formation in the progression from engineering graduate to registered (chartered) engineer status. (This is an area of educational business opportunity that has been largely ignored by universities.)

The undergraduate program and curriculum needs to increase the time devoted to the development of the knowledge, skills and graduate attributes that are essential for the functions associated with engineering activities: communication, teamwork, leadership, responsibility, ethics, sustainability, risk, project management, costing and financial management, contracting, specification, etc. As a consequence of achieving this essential transformation, the proportion of time devoted to the specialist technology components should be reduced while the project, design and realisation elements are increased. This can realise some increased emphasis on creativity, innovation, social responsibility and professional capability.

A specialist content stream is important to demonstrate to students what is involved in moving to the forefront of a particular topic. It should give them confidence that they can do this in another field when required, rather than commit them to operate in this particular sphere of technology for their entire career, which is quite unusual. With the broadening of interaction across technical fields there is also scope for greater breadth and less specialisation in the final years of programs. The need for greater emphasis on a systems approach to the technical component of the course may prove more advantageous for many students.

Another important consideration is that of devoting appropriate attention to the issue of environmental sustainability. Sustainable development is a professional obligation for all engineers. It cannot be left to specialist environmental engineers. Sustainability is an issue that should be considered in all engineering projects and pervade the curriculum development considerations. The Contributed Panel authored by Mulder, Desha and Hargroves explores this issue in a manner helpful to those responsible for program design and delivery.

Making major modifications to the curriculum will be difficult for universities. They have complex policies, procedures, practices and requirements which have been implemented to meet the conflicting interests of the many stakeholders (Section 4.4). The issue of achieving transformation within universities will be addressed specifically in Sections 7, 8, 9 & 10.

Contributed Panel No.10:

Sustainable Development as a Meta-Context for Engineering Education

K. F. Mulder, C. J. Desha, K. J. Hargroves

Respectively Delft University of Technology, Queensland University of Technology, Curtin University

(This paper was first presented at the 6th Dubrovnik Conference on Sustainable Development of Energy, Water and Environmental Systems, 25-29 September 2011)

Summary

At the end of the first decade of the twenty-first century, there is unprecedented awareness of the need for a transformation in development, to meet the needs of the present while also preserving the ability of future generations to meet their own needs. However, within engineering, educators still tend to regard such development as an ‘aspect’ of engineering rather than an overarching meta-context, with *ad hoc* and highly variable references to topics. Furthermore, within a milieu of interpretations there can appear to be conflicting needs for achieving sustainable development, which can be confusing for students and educators alike. Different articulations of sustainable development can create dilemmas around conflicting needs for designers and researchers, at the level of specific designs and (sub-) disciplinary analysis. Hence sustainability issues need to be addressed at a meta-level using a whole of system approach, so that decisions regarding these di-

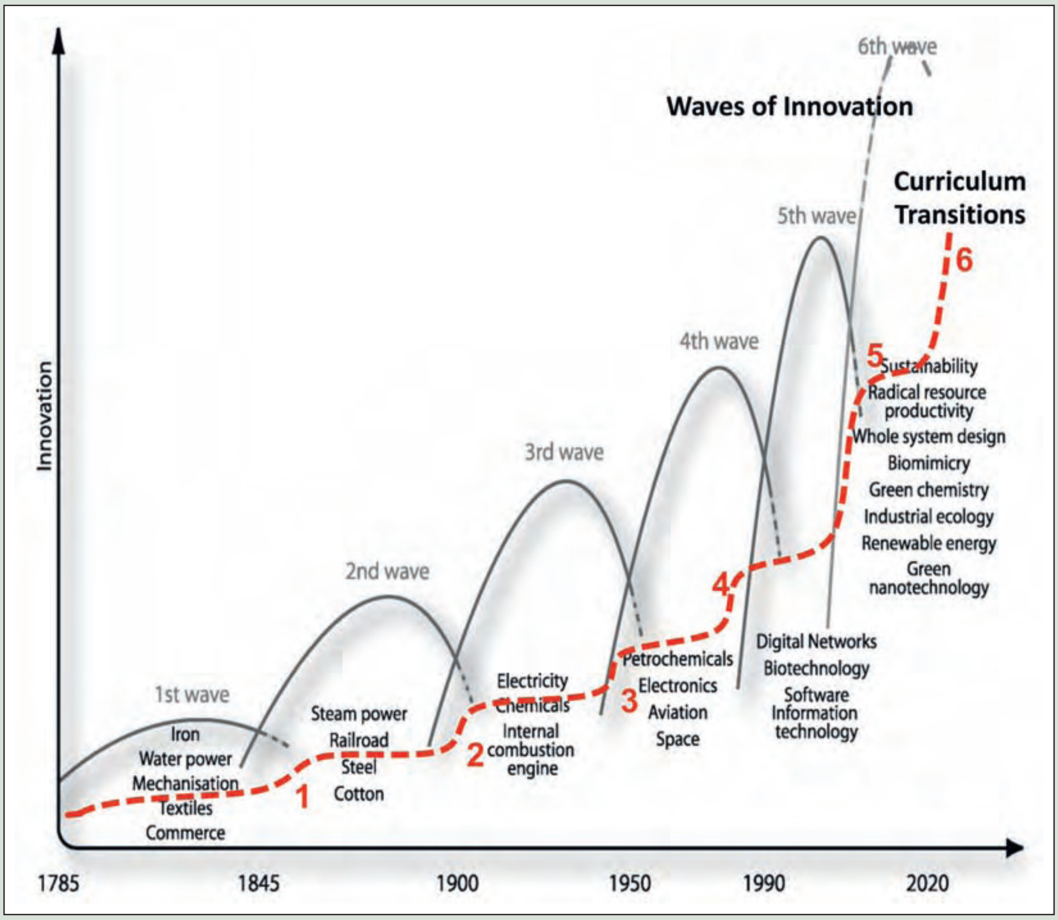

Figure 1: A schematic of curriculum renewal transitions, following significant waves of innovation [6].

lemmas can be made. With this appreciation, and in light of curriculum renewal challenges that also exist in engineering education, this paper considers how educators might take the next step to move from sustainable development being an interesting 'aspect' of the curriculum, to sustainable development as a meta-context for curriculum renewal. It is concluded that capacity building for such strategic considerations is critical in engineering education.

Engineering Education and Sustainable Development

At the aggregate level of the whole planet Earth and global society, sustainable development is clearly defined, with many textbooks on the topic and the role of education.[1,2,3] Indeed, in commenting that *'Engineers play a key role in sustainable development'*, one can achieve a pleasant start of any discussion on the topic in the engineering community. Such a discussion soon highlights how sustainable development is not about blaming technology and industry for the polluting and wasteful society that we live in but rather that engineering is a key part of the solution in successive waves of innovation[4,5]. As shown in Figure 1, the fifth wave of innovation, which occurred towards the end of last century, provided a new technological platform and numerous tools for development. However, alongside these achievements, society now faces a host of emerging challenges and opportunities under the sustainable development umbrella. These may include reducing greenhouse gas emissions, addressing climate change adaptation needs, diminishing the equity gap, dealing with resource scarcity and creating solutions that decouple economic growth from negative environmental pressure.[6]

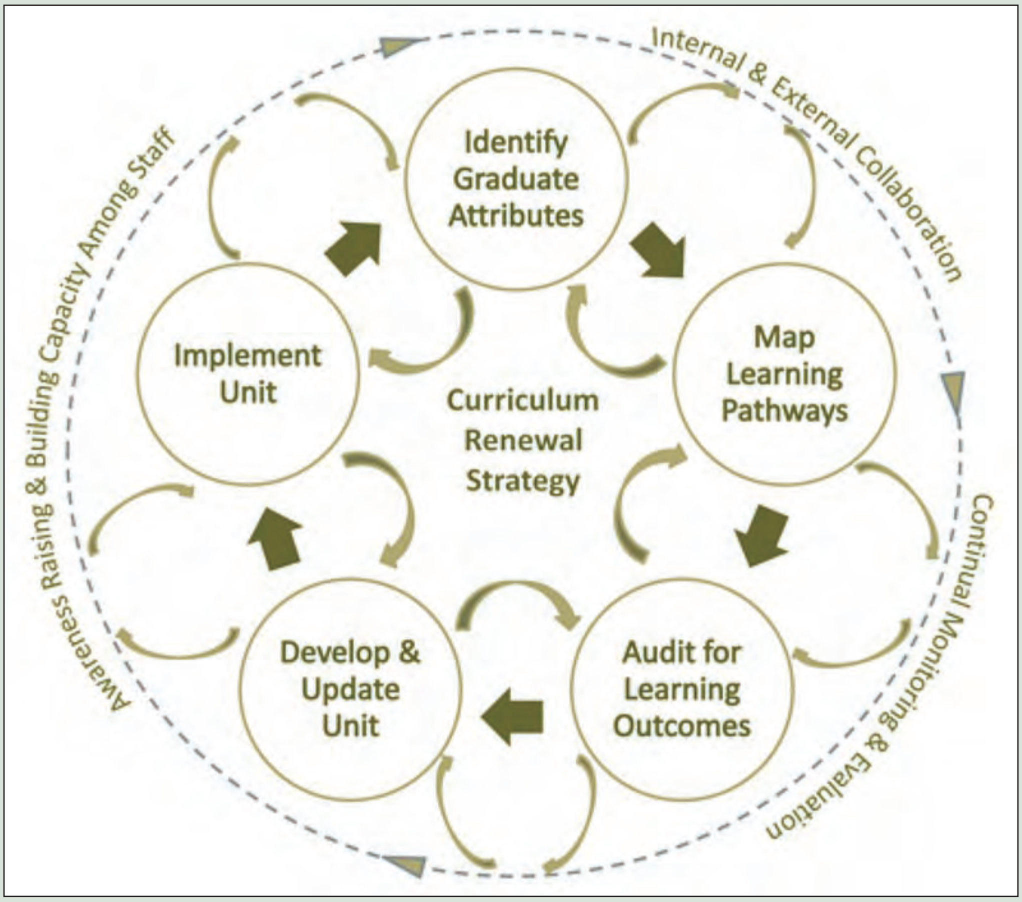

Figure 2: The Desha-Hargroves Deliberative and Dynamic Model for Curriculum Renewal [6].

In the sixth wave, the engineering profession plays a key role in responding to these emerging challenges, drawing upon knowledge and skill sets across all disciplines in new areas such as resource productivity, energy efficiency, whole system design, and bio-mimicry (i.e. design inspired by nature). Within this context, if engineers have such a crucial role they should know where they are heading, and their curriculum should enable them to pursue that pathway. Unfortunately, more than two decades after seminal publications such as 'Our Common Future'[7], and with cautionary reminders such as the *'Stern Review'* [8], *'Plan B'* [9] and emerging engineering related sustainability text books such as *'Factor 5'* [4] and *'Cents and Sustainability'* [5], around the world sustainable development still appears as add-on modules in the curriculum, with limited knowledge and skill development or embedding through content and assessment.[10]

Globally there are few engineering programs that may claim to have embedded sustainability within the curriculum.[11,12,13,14] Instead, most engineering programs still define themselves as a discipline which means that there is a core set of knowledge. Then, sustainable development is one 'aspect' or consideration to be covered as far as it touches their particular discipline, for example in civil, electronic, environmental, and mechanical engineering and so on. Furthermore, the traditional amount of time needed/ required to undertake a full-scale curriculum transition (in the order of two decades) is exceeding the available window for equipping professionals with critical new graduate attributes. This is a significant time lag dilemma facing educators, and is highlighted by the dotted line in Figure 1.[10] There are few examples of systemic curriculum renewal that meet the recommended timeframe of one decade, or discussion of how curriculum renewal could be undertaken over such contracted timeframes.

A significant challenge within this state of affairs is that by sustainable development being merely an additional aspect of each discipline's considerations, it does not provide the central (or underpinning) context for the curriculum. Furthermore, an aspect may be dropped or replaced due to any number of bureaucratic pressures without much ado. In summary, being an aspect lends the topic area to vulnerability, where critical knowledge and skill areas may be deleted or replaced without systemic consideration of learning consequences.

With this in mind, the question we consider herein is how might engineering educators take the next step: moving from sustainable development as an interesting aspect for the engineer, to sustainable development as a meta-context for curriculum renewal? Furthermore, in a profession with many sub-disciplines and various phases of design, how do we develop a curriculum that avoids creating dilemmas around conflicting needs for designers and researchers?

Engineering Education & Curriculum Renewal

Intertwined with the challenge of embedding a substantial new knowledge and skill area within the engineering curriculum, Desha and Hargroves highlight the challenge of undertaking the process of engineering curriculum renewal itself.[6] The last century's engineering education literature clearly highlights a shortfall in the ability of the curriculum to respond to changes in graduate demands. In particular, enquiry by these authors into a number of earlier models by leaders in the field over the last half century, including Tyler, Taba, Wheeler, Kerr, Walker, Stenhouse and Egan, uncovers a lack of a whole of system approach to curriculum renewal in the higher education sector that has two significant implications:

- The *ad hoc* process inevitably leads to delays and inefficiencies in curriculum renewal processes; and
- There is no systematic way to build central themes and meta-context into the curriculum.

It is no wonder then, that there have been so many difficulties in embedding sustainability into the curriculum to date. In responding to this challenge, Desha and Hargroves have developed a model that can provide a strategic framework for renewal, wherein any new knowledge and skill set could be systemically embedded into the curriculum.

Beginning with the curriculum renewal strategy (centre of diagram), this model highlights the importance of having a central point of reference when undertaking systematic curriculum renewal, particularly when multiple educators are involved (in this case the context of 'education for sustainable development'). The arrows immediately around this text remind us that the strategy needs to inform each and every stage of curriculum renewal. In the five larger circles around the central strategy, the five key steps in curriculum renewal link in an iterative process that reminds us of the need for substantial planning and investigation before individual units are revised. The arrows interacting with the outer circle remind us that this stepped process also requires continual monitoring and evaluation, internal and external collaboration, and awareness raising and capacity building among staff. Furthermore, the steps are informed by, and also inform, the three activities in the outer circle.

In summary, by using such a model, a whole of system approach to curriculum development can be taken that firstly, makes possible the creation of a framework for educators to articulate sustainable development as a meta-context of the curriculum, and secondly, encourages a whole system approach to considering sustainable development issues.

Sustainable Development as a Meta-Context

Engineering curriculum often addresses sustainable development as an 'aspect' of engineering rather than a central agenda, with ad hoc and highly variable references to topics ranging from pollution and resource consumption to safety, energy efficiency, recycling, fair trade, livelihood and public health. As long as that is the case, sustainable development will remain a consideration to be balanced by other aspects, like economic development and the financial wellbeing of the university, learning and teaching ambitions, or other agendas that flow through the higher education system. Unfortunately this kind of scenario is evident in numerous codes of ethics statements and graduate attribute expectations around the world.[14]

In fact, while numerous discipline-based 'aspects' are covered by sustainable development, they are not often considered systemically nor understood for their nuances within each discipline. This is evidenced in research currently underway. For example, in Australia a project is currently underway, funded by the Federal Department of Resources, Energy and Tourism, to inquire into energy efficiency education and articulating meaningful graduate attributes and learning pathways for each of the major engineering disciplines. Engineers Australia is also seeking to encourage the embedding of sustainability within engineering curriculum. Alongside this endeavour, a systemic inquiry project is underway to define various disciplines, funded by the Australian Learning and Teaching Council, with one of the projects considering how twenty-first Century considerations are embedded within environmental engineering.

Essentially such research points to a key problem, being that even in communities of practice related to sustainable development, the understanding of the term is often poor. The Brundtland definition of 'sustainable development'[6] is clear at the aggregate level of the whole planet Earth and global society. It remains challenging to distinguish what 'sustainable development' means within individual disciplines, or for various sub-topics, as there is no indisputable explanation/ definition that prescribes how the global challenges should lead to individual action within those disciplines and sub-topics.[16] Further, a range of potential solutions have systemic implications that need to be considered across disciplines. For instance, should we increase bio-fuel production, or diminish it, to protect biodiversity? Should we recycle plastics, even if it creates safety risks and uses large amounts of energy? Ideally, engineering education should make students aware of these, and many other dilemmas associated with achieving sustainable engineering solutions. They should also be made aware that solutions are found through interactions with other disciplines and a range of stakeholders, through a whole of system approach.

The fact that a parameter (in this case sustainable development) is only meaningful at a specific level of aggregation is not new to engineers: For example, while in physics the concept of density is not applicable at sub-atomic level; still, characteristics of the atom are not irrelevant for density of a material. The same holds for sustainable development; while it may not be an appropriate 'category' to apply to a single technology, still, characteristics of the technology are relevant in considering whether sustainable development has been achieved. In saying this, if a whole of system approach to considering sustainability issues is not taken, then there may be a perception of conflicting needs to meet 'sustainable development'.

For example, considering the supply of power, certain aspects of delivering 'safe' power may not be the most energy efficient, however if we consider the notion of sustainable energy supply as a meta-context, it includes safety as a requirement. In another example, manufacturing low-embodied energy and low energy consuming white goods might require the use of almost depleted minerals. However, if we consider the notion of low carbon products, then the use of finite resources might be a requirement to achieve such a goal, with measures such as subsequent recovery at the end of the product life. Clearly, given the wide variety of contexts faced in any design scenario, engineering educators should not prescribe their students what to do when confronted with such dilemmas. Rather, there is a need for educators to develop the capacity of students to deal with these situations in a whole of system approach that is most likely to create consensus among stakeholders and action towards improvement.

Given the emerging opportunity for systematic curriculum renewal, and given the need to clearly articulate sustainable development for all types of engineering, there are a number of emergent findings that span individual subjects through to accreditation considerations:

- Engineering practice has as a core driver, 'doing things efficiently'. However, the question of 'how do we know what should be done?' should be a meta-context for the curriculum, to avoid the potential for 'doing the wrong things efficiently'. This includes for example addressing ethical considerations and dealing with community needs as central features of the engineering curriculum.[17, 18]

- At the level of engineering courses/ subjects, statements about learning outcomes (which are intended to promote education for sustainable development) will also need to be specific to the actual knowledge or skill being developed, in the over-arching context of a whole system approach. These would be more effective than broad-brush and ad hoc statements that are not conducive to learning or assessment.

- At the level of engineering programs, generic statements may be counter-productive to curriculum renewal for sustainable development. Hence, statements about engineering graduate attributes will need to be more specific than simply stating competencies in 'sustainable development', and must articulate how a whole of system approach to engineering will be developed.

- At the level of directing capacity building (through engineering professional bodies and accreditation agencies), expectations about program and graduate competency requirements will need to be explicitly stated for whole of system considerations, during curriculum renewal towards education for sustainable development.

Conclusions

This paper has highlighted the phenomenon of how different articulations of the term 'sustainable development' can create dilemmas, particularly in the absence of a meta-context or whole of system approach. There is clearly a need for systemic appreciation of the term by engineering educators. Indeed, only by understanding the role of various articulations of sustainable development, could one proceed in actually making sustainable development the organizing theme of sustainable engineering curricula. With this context of systemic appreciation in mind, sustainability issues can then be addressed as a meta-context, avoiding the creation of dilemmas at the level of sub-discipline or design component. In conclusion, it is an urgent matter that engineers need to be skilled in whole of system processes that strategically consider sustainability issues, so that future solutions do not create future problems. This will involve action at multiple levels, from the individual subject and program through to professional discipline leadership in defining graduate attribute expectations and accreditation implications.

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5.2 Project Based Learning

Project Based Learning (PBL) is a widely reported [57] [58] [59] approach to address the need to change engineering education, from the formal presentation of technical material to a student experience model. It provides activities which simulate the role and responsibilities of practicing engineers and develops the general graduate attributes that have been identified as essential. It was first used in medical education and is now extensively used as it promotes the development of the skills and knowledge required by medical practitioners. PBL is also used for problem based learning which has a much longer history. It is not inconsistent with Project Based Learning and it has been considered to be a sub-set of Project Based Learning. It is also called Project Centred Learning (PCL), a title which describes how the projects become the focus for the student's learning activities. PBL can involve projects of widely varying scope and complexity, and commonly involves learning teams. Another closely related educational philosophy is inquiry-based learning which is used to describe the learning process followed by the individual students.

A study by Mills and Treagust [60] concluded "that the use of project-based learning as a key component of engineering programs should be promulgated as widely as possible, because it is certainly clear that any improvement to the existing lecture-centric programs that dominate eng-ineering would be welcomed by students, industry and accrediting authorities". Project Based Learning can be organised for individual work, but there is greater benefit from having the project undertaken by a team of students. This relates more closely to a realistic engineering environment, provides an opportunity for students to learn from each other, and assists the development of the essential graduate attributes of teamwork and leadership.

The University of Aalborg (Section 4.6.4) was a pioneer of project based learning, introducing this approach from the inception of the university in 1974. PBL comprises approximately 50% of their total curriculum being used in each semester of the 7 semester engineering degree programs. It is been shown to be popular with the students who value the skills that they have acquired through the program. The student groups comprise 5-7 students and 2 staff members are responsible for the oversight and facilitation of each project group.

PBL has been most widely used for the development of an engineering perspective in the first year of engineering courses, where it fulfils an important role of improving motivation and reducing the dropout rate, within a multidisciplinary environment (See Section 4.7). Being part of a group is important to assist student adjustment to the new learning environment. However its advantages should not be limited to first year. It is also, of course, extensively used in the form of the capstone design project as a key component of final year in almost all courses. So the extension of PBL to all years seems to be a very logical and achievable strategy. The assessment of PBL projects raises a number of issues because of their inherent team nature and this topic is addressed in the Contributed Panel authored by Dr Prue Howard.

Projects of this type are typical of how engineers will operate throughout their professional career and the benefits of continuing this educational component through all the semesters of an engineering program are considerable as it would ensure that students are job ready and have developed the required graduate attributes. Projects can have a different emphasis as they progress through their program. Variations in the following parameters can be made: difficulty, scope, discipline specificity, complexity, collaboration, investigative requirements, competitiveness, form of reporting and presentation, theoretical depth, design emphasis, physical realisation, environmental issues, social impact, community involvement, business and financial aspects, industry involvement, ethical complexity, novelty and the need for innovation. PBL also provides an excellent vehicle for the development of teamwork, leadership, responsibility, independent learning, self-management, communication skills, information acquisition, system thinking and creativity. An incentive to acquire knowledge of the scientific principles and the mathematical tools that are essential for engineers is also created by the projects. Exciting innovations can result from these projects.

PBL is also able to be readily adapted to address specific national development requirements. The scope available for project based learning to deliver positive benefits to engineering education is only limited by our imagination. Environment and development related projects are almost limitless in scope, and in addition to being important, they give an opportunity for students to address the issues of social responsibility. These projects also open up opportunities for cooperation between groups in different universities and in different countries. In a knowledge–based economy independent judgement is often essential for problem solving, service provision or product development. PBL is an ideal activity to enhance the attributes necessary for these activities. It is the ideal educational strategy to develop the qualities for innovation upon which our societies depend.

There is an excellent match between the education benefits provided by Project Based Learning and the Graduate Attributes required for Professional Engineers. It is not clear how these benefits could be more effectively delivered by any other educational processes or strategies.

It is now possible to identify that:

The fourth step towards Transformation is the utilisation of Project Based Learning in each year of engineering education programs.

Contributed Panel No. 11:

Assessment in a PBL Environment

Dr Prue Howard

Central Queensland University (CQU)

Assessment in a PBL environment is different to other environments. Why? Because the context is different – the learning is expected to occur in a team environment as opposed to considering an individual learning alone or developing a team outcome, the project or problem, is the context for learning, as opposed to the assessment item, and there is an expectation that there will be an integration of knowledge and skills with the unit of study, as opposed to the concentration of a content area. These issues mean that in a PBL environment, facilitators need to assess an individual, when their work and learning is done in a team environment.

Grading individual students in teams has always been problematic. To accurately gauge individual learning outcomes, students' grades need to be based on what they have learned as an individual within the team context. However, within engineering team-based projects, individuals have traditionally been assigned a grade heavily influenced by the team's project outcomes. Consequently, a poor project outcome for a team results in poor grades for its individual members, even if significant individual learning occurs. As assessment drives behaviour, the desire for higher grades influences the team dynamics resulting in an emphasis on project outcomes rather than individual learning, potentially degrading collaborative learning.[1,2] While some research has been conducted on team formation and monitoring to help reduce these effects, such as the 2007 Carrick project "Developing and disseminating TEAM SKILLS capacities using interactive online tools for team formation, learning, assessment and mentoring"[3], it does not assess individual learning in teams.

The recent project "Engineers for the Future"[4] recommends the development of best-practice engineering education to promote student learning and deliver intended graduate outcomes. This project follows the 1996 report "Changing the Culture[5], which first highlighted the need for change to an outcomes-based engineering education system in Australia. Implementing changes to student learning and graduate outcomes have since resulted in a greater emphasis on team-based projects. This requires a dramatic change to the traditional methods of assessing individuals within teams in engineering as they do not currently meet the assessment needs of practice-based education, such as project-based learning.

Although some institutions have implemented the changed curriculum in response to these developments, there has been little research conducted into appropriate assessment methods to suit the new outcomes requirements. In some programs, particularly those using PBL, there has been recognition that traditional assessment methods are inappropriate[6]. Quantitative methods of assessment discourage collaborative team learning and instead drive competitive behaviour, which is counter-productive to the required learning outcomes. Qualitative processes are more likely to result in the required collaborative learning. Some programs have attempted to address this issue and introduced assessment processes that are used in other disciplines, such as portfolios. Australian examples of this are CQU and Victoria University (VU) where such assessment strategies have been implemented at a program (or degree) level, as opposed to ad hoc in individual units of study. However, the lack of evidence within the discipline to support the use of qualitative assessment methods has resulted in a lack of trust by the accreditation body in these assessment processes. Consequently, this has posed a major challenge for institutions seeking to embed new assessment practices within programs, which are dependent upon accreditation.

Qualitative assessment methods are more suited than quantitative methods in assessing graduate attributes in PBL in terms of the broader, professional, context-dependent skills required of an engineering student. These contrast with the quantitative assessment methods generally used in engineering courses that make up a program of study to assess specific, technical content knowledge, which tends to require right or wrong processes and answers. The majority of engineering academics and industry professionals understand and are more comfortable with quantitative assessment methods. Experience with accreditation teams shows their mistrust of qualitative assessment, with teams often commenting that qualitative assessment is subjective and is therefore not a valid or reliable method of assessment in engineering. Within the Australian context, the engineering discipline does not have a valid method for qualitatively assessing individual learning in a team environment accepted by the Australian accreditation body for engineering programs (Engineers Australia), as well as engineering academics and industry. This is a major challenge to the acceptance, accreditation and implementation of PBL-based assessment of individuals in teams. However, it is also an issue for all engineering programs, which must demonstrate graduate outcomes from complex tasks such as final-year design and research projects.

The basis of grading decisions in practice-based education such as PBL needs to disassociate the learning environment (the project) from the result (grade) and instead focus on an individual student's learning.

PBL-based units of study differ significantly from traditional engineering courses in that the project forms the context for student learning, instead of being the assessable deliverable for the course. The project provides an ill-defined engineering problem in which students learn in a team environment. Students must, with the help of facilitated learning sessions and self-directed learning, identify what knowledge and skills are required to complete the project, which of those exists within the team, and which must be gained and applied to the project.

CQU, VU, and Aalborg University (Denmark), are three institutions that have a program level (degree level) PBL philosophy. These three institutions have already undertaken preliminary work in developing robust processes to assess individual learning within PBL teams. For example, CQU and VU use portfolio-based assessment to make grading decisions, whereas Aalborg University uses an oral examination. These assessment methods focus on evaluating individual learning rather than project outcomes.

These institutions use an assessment model where the team projects are the learning environment and the portfolios or oral examinations are the individual's summative assessment—a model of assessment that has been accepted in many disciplines that are qualitative in nature, such as education and human factors. In engineering education, portfolio assessment is used in a range of institutions internationally.[7, 8, 9, 10, 11] However, these methods of assessment are currently viewed with scepticism in engineering programs within Australia. Such models have been the subject of teaching and learning research[12], but the assessment models and grading decisions used must be capable of withstanding external scrutiny, that is, they must be accepted as valid by the accreditation body for engineering programs to embed these assessment models within institutional practice.

A current Australian project "Assessing individual learning in teams: Developing an assessment model for practice-based curricula in engineering" is using Grounded Theory to develop an assessment framework to use in a PBL environment. The framework recognises that while the curriculum starts with aims and needs, the students start with assessment; therefore the assessment needs to be carefully structured to ensure that the student learning achieves the desired outcomes.[13]

Some further factors that must be considered in assessment in a PBL environment are:

- Assessment is a significant 'driver' of student learning.
- Collaborative learning emphasises not just learning content, but also the refinement of the learners as they enter the community of practice of engineering.[14] It therefore focuses on how the world view of the students is changed as this refinement takes place. Assessing this change requires holistic assessment.
- The role of assessment in a learner-centred approach like PBL is somewhat different from that in more teacher-centred approaches. While most students (and many staff) see assessment only as a tool for measuring how much they have learned (assessment of learning), in PBL there is a strong emphasis on using assessment to support and direct student learning (assessment for learning).[15]

The current project, "Assessing individual learning in teams", started by investigating the following points:[16]

1. What methods are currently in place at member institutions for assessing an individual student's learning in team-based coursework?

2. What connotes the effective assessment of an individual student's learning in a team-based course?

3. What challenges and opportunities do individual instructors (as well as teaching teams) face when first implementing the first iteration of our strategic assessment framework?

4. How can these opportunities and challenges shed further light on the complex context of assessing individual student learning in the team-based learning environment and on the efficacy of our new-formed strategic assessment framework?

Preliminary thematic analysis revealed a range of considerations that participants employed when designing and implementing assessment of both individuals and teams. These considerations included contextual considerations for assessment (such as the number of students in the subject), considerations about assessing types of learning (such as design thinking or technical knowledge), and considerations about the team context (such as determining an individual student's level of engagement in team products).

The outcome has been a conceptual framework that was piloted in four Australian universities in 2011.

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5.3 Student Centred Learning

Since the education program exists to develop students to their potential, it follows that the education process should be student centred to maximise learning. However, the majority of education is staff centred! Why is this so? How can student centred learning be provided? What can be done to change current practices?

The model upon which universities have been established is that their academic staff are experts in their discipline, and they provide access to their accumulated knowledge for the scholars who are seeking to become knowledgeable in that field. The academic staff member plans and controls how they communicate their wisdom, facilitates its interpretation and then assesses and certifies those who have achieved the standard of understanding which they consider appropriate. While this method started with small groups in a discussion based tutorial approach, it has been inevitable that groups seeking knowledge would expand so that a lecture model evolved where the communication process became primarily unidirectional. Most university teaching is via a lecture model, usually supplemented by a mix of activities selected from seminars, tutorials, reference material, laboratories and projects. Lectures were an inevitable evolution from small group discussion when the numbers of students expanded dramatically, especially when cost control of university activities became a necessity. Large lectures do allow many students to hear an expert.

The lecture based approach to education is staff centred. It has been described, in jest, as the process of transferring information from the notes of the lecturer to the notes of the student without passing through the mind of either party. Subsequently the process was dominated by the overhead projector and now it is the Power Point display. It does not provide an effective learning experience for students. As it is normally used, it is an information transmission exercise. However, in this age of information we have text-books, lecture notes, web-sites and internet if we wish to convey content. As there are far more efficient information transmission mechanisms than lectures, why are they so commonly used? Why does the lecture remain a dominant educational medium when it has been proved to be an ineffective device to promote learning? Lectures are routinely rated as boring by students. Of course there are some excellent lectures and lecturers, but that is the exception rather than the rule.

Lectures have been part of university culture for a long time because of the familiarity of academic staff with the method, having survived it when they were students. Lectures have become the convenient norm for unquestioning institutions. It is widely used because it is the easiest (least demanding for staff) form of contact with students and because it is economical when large student numbers are involved. It can be presented with little preparation (especially following initial preparation). In the lecture situation the lecturer is in control of the students. The lecturer's authority is supreme. Students, however, believe that the lecturer is telling them what they must learn for the examination and diligently endeavour to record as much as possible for future reference.

Professor Eric Mazur of Harvard University has conducted very interesting research into the effectiveness of his Physics lectures to pre-medicine students [61-63]. He commenced his lecturing career, as many others, by focussing upon what he was going to talk about, instead of focussing upon how the time could be used to assist the students to learn. He discovered that, although his lecturing ticked all the normal boxes as being effective, upon analytical examination it became apparent that they added little to the students understanding. He was conveying information, but the lectures did not achieve the conceptual understanding which was essential for his students and for which he was evaluating them. This experience led him to pioneer a new way to use the time that he has with his large group of students. He has designated it the Peer Instruction Method (PIM). Its features are:

1. Reading is assigned to be undertaken by all students prior to each period.

2. He makes no presentation of material.

3. He presents the students with a question that tests their conceptual understanding of the prior reading.

4. The students make their individual choice of the correct answer from 4 multiple choice answers in a suitable given thinking time (approx. 1-2 minutes) indicating their answer, by a push button selector, to a theatre computer system which displays the accumulated response to him.

5. The students then have 3-4 minutes to justify and discuss their answers in self-selected groups of 3-4 students who are seated near each other.

6. They then vote again by push-button.

7. He will then indicate the correct answer.

8. He then proceeds to the next question which will be chosen from his pre-prepared questions, answers and distracters according to his assessment of the most appropriate topic in view of the understanding demonstrated.

9. The process is repeated with the next question.

10. He has indicated that he prepares approximately 12 questions with multi-choice answers for each class and uses approximately 6. No questions are reused in subsequent years.

11. The student's answers are not used in determining the grade they receive for the subject.

The Peer Instruction Method has utilised the constraints of a large student group format to generate a student centred learning experience that focuses upon conceptual understanding instead of information transfer. Professor Mazur has experimentally verified the effectiveness of the method, showing that it doubles the benefit gained from a traditional lecture course. It is a method worthy of widespread use in engineering courses. It would be important to explain very thoroughly to students what is to be done and why, so that they were committed to the approach.

There are, of course, many effective strategies to provide student-centred learning or active learning. Project-based learning discussed previously is one approach that is particularly important as it is ideally suited for engineering education. However, it is important to further examine the fundamentals of this issue as the problem of moving the universities away from the lecture dominated educational paradigm to more effective learning activities is an issue of enormous importance. It is clear that the active participation of the students is essential for learning to occur and that there is a correlation between the amount of active participation and the effectiveness of the learning.

5.4 A Pedagogical Perspective

Education is the process of learning the necessary skills, capabilities and knowledge to be able to perform a specific role, which for our considerations is the preparation of the student for the role of an engineer when they graduate. It is the responsibility of the academic staff to provide efficient assistance to students, as they work towards the achievement of their personal development goals. In specifying and interpreting the curriculum, the academic staff determine the learning priorities of the students and specify the learning experiences that they undertake, and consequently they influence how the students utilise their time. Learning is dependent upon the achievement of understanding. Understanding must be built by the individual learner through the performance of tasks. It is facilitated by feedback from teachers or peers. Conceptual learning depends upon thinking and understanding. It is realised progressively as the student pursues a journey in the personal, social and organisational context, It benefits from activities and experiences that deepen and broaden the student's thinking. The academic's effectiveness is greater if they can encourage activities which stimulate this depth of thinking by the students. Learning-by-doing works best because performing a task requires the learners to think and comprehend at the most demanding level, which is that associated with problem solving. Since problem solving is a core activity for engineers, project based learning, problem based learning and exercises that generate thinking, should be the core of an engineering education program. It must be agreed that the lecture process does not satisfy this pedagogical model.

Bloom's Revised Taxonomy of Cognitive Abilities [64] is useful in planning the experiences which will develop the student's capabilities, as the practice of engineering relates to the higher order abilities. In ascending order of complexity they are:

1. Remembering
2. Understanding
3. Applying
4. Analysing
5. Evaluating
6. Creating

Considering its application to the development of engineers, the acquisition of Knowledge results from the achievement of Understanding, Skill has been attained if there is a capability for Applying the Knowledge, and the Ability to undertake actual engineering functions comes when there is a capability for Analysing, Evaluating and Creating. If educational programs can develop the skills for knowledge acquisition and encourage experiences for its application in situations that require creative solutions, they are going to develop effective engineers. Of course the test of the effectiveness of program design is related to the efficient and effective achievement of the specified graduate attributes.

There are various theories of how educational programs can most effectively produce student learning. A paper by Astin [65] which resonates with the authors' experiences proposes that "The amount of student learning and personal development associated with any educational program is directly proportional to the quality and quantity of student involvement in that program". The effectiveness of any educational policy or practice is directly related to the capacity of that policy or practice to increase student involvement." This Student Involvement Theory is contrasted with the Subject-Matter Theory (or Content Theory) which is the most commonly practised method. It assumes that student learning and development is primarily dependent upon the student's exposure to the right content, appropriate syllabi and results from attending lectures, undertaking assignments, and working in the library. The widely utilised lecture-based approach to teaching is the key presentation vehicle for those committed to the Subject-Matter Theory. Another theory, which is favoured by administrators, is the Resource Theory which assumes that when adequate resources are brought together then student learning and development will occur.

The Student Involvement Theory of student learning and development should guide the design and delivery of engineering education programs. It is consistent with project based learning, student-centred learning, learning communities, teamwork, home rooms, e-learning, student networking, the importance of student motivation and the emphasis given to the development of graduate attributes, documented through their own e-portfolio. It also emphasizes the perspective that the course content is of lesser importance than the experiences that the students undertake to facilitate their development, as they seek to move towards realising their goal of becoming effective and responsible engineers.

Another example which demonstrates very well that there are more effective alternatives to the traditional lecture method, are the experiments which were conducted by Professor James Gibbons of Stanford University [66]. Live lectures were telecast from Stanford for the simultaneous use by on and off campus electrical engineering students with an audio link for questions for those in industry employment. In the period before satellite and cable television, industry requested advice as to how this service could continue for their employees when they were sent to work in other cities where a live link was not available. Out of concern for their disadvantage, in being unable to interact with the lecturer, a method was devised to compensate. It involved sending a videotape of the lecture (as this was available from the direct telecast) to the distant employers. They were then required to arrange for the students to watch it, in groups of about 8-10, with a non-expert facilitator who would stop the tape each 10 minutes to permit group discussion (for about 10 minutes) with the objective of identifying all unresolved questions for forwarding to the lecturer. Answers were then to be provided for their next tutorial group meeting. The results were analysed carefully and it was found that the tutored videotape instruction (TVI) group outperformed the students in the other two groups quite spectacularly. The results showed that the students whose previous performance had been poorer improved the most, as was discovered in the PIM evaluation (Section 4.3). Also as in the PIM system, the inclusion of a student thinking activity, which occurred in the student discussion without expert participation, was important in improving their understanding. The student's interactive discussion led to very few questions being sent back to the lecturer. Also the absence of an "expert" encouraged student discussion. This important experiment was repeated with the same result using students at different levels and in different fields and circumstances with the same result. It shows that while lectures convey information, along with books, computers, television, etc., they are not effective at generating understanding. This requires the active participation of students. It also demonstrates that some of the students who are unable to pass, in a lecture based model of education, fail because the lecturer, using the traditional lecture format is unable, to stimulate their student's thinking sufficiently to generate their understanding of the topic. These methods also demonstrate that student interaction is an effective contributor to the learning process and that it should be a planned component of the learning experience. The role of lectures is as a special occasion activity where the aim is to convey information that is not available in another format.

It is now possible to identify that:

The fifth step towards Transformation is the replacement of the information transmitting lecture in engineering education programs with activities that generate student centred learning through the active involvement of students which creates thinking aimed at developing understanding.

5.5 New Technology in the Learning Process

The educational process has been significantly impacted by the rapid development of new information and communication technologies (ICT). They are impacting education at all levels and the change process will continue to accelerate for many years as ICT systems are continuing to develop with even more effective capabilities to enhance the learning experience. [67] [68]

The ICT revolution has the capacity to radically change the engineering education system and the processes utilised by universities. The use of ICT has increased rapidly since the eighties with the dramatic increase in the capabilities of computer hardware and software, coupled with the availability of low-priced personal computers, and the expansion of the world-wide-web. It has also changed the role of engineers as the profession now finds ICT indispensible in all aspects of its activities. Computers have enabled solutions that are dependent upon very complex calculations to be more easily realised. They have also enabled complex engineering systems to be modelled and the solutions for differing situations to be explored. It has also changed the nature of the technological solutions that can be implemented through the use of embedded computer control and complex data acquisition systems. Such complexity is increasingly demanded by the profession's clients and becomes essential to provide the functionality demanded of engineering solutions. The capacity of modern enterprises to compete effectively is largely determined by their ICT application platforms.

Educational practices using ICT can have a learner-centric orientation and reflect advanced, evidence-based knowledge on learning and cognition. The learning materials and associated practices would be generated by an active community of academic staff, and occasionally students, who create, share, evaluate, and modify them. This community would embrace a scholarship of teaching and learning and have a continuing goal of advancing learning. The dissemination of IT-enabled teaching and learning resources should be supported by a legal framework (e.g., creative commons, open licenses and attribution systems,) that promotes creation and sharing, while maintaining incentives for authors (including individuals, teams, and institutions) to create and distribute high-quality learning materials.

The impact of ICT upon engineering is multi-dimensional. It has increased the importance of systems engineering as many engineering solutions are now multidisciplinary, involving real-time data monitoring, communication, computation and control. It has enabled the technologies of robotics, automation, satellite monitoring and positioning, micro-engineering and many others. It has transformed the tools available to engineers for computation, simulation, modelling, designing, drafting, specifying, costing, tendering, planning, testing and managing projects of any scale. The rapidly developing ICT technology has led to the need for engineers to constantly update their knowledge by accessing current information rather than relying on what they learnt at a previous time. The development of professional capabilities in engineering graduates now necessitates that engineering students have the opportunity to develop an understanding of the use of some of these advanced engineering software tools during their educational program.

ICT technology is the key enabling technology which can be used by engineering academics to enhance the effectiveness of the learning process for their students as it provides new paradigms for establishing communication with, and between, staff and their students and for obtaining and delivering information. It can facilitate the shift from staff teaching to student learning. However ICT has made considerably less impact on the core roles of engineering academics than those of other engineering professionals. Computers have become indispensible tools in the design of all complex systems and are used for modelling, simulation, analysis, evaluation, visualisation, documentation, detailing, project supervision, manufacturing, ordering, testing, monitoring and communication.

Why have universities been slow to maximise the value of the most important revolution in the information industry of which the education industry is part? While there are some exemplary exceptions, the most common use of ICT technology by academics is still Power Point, which increases the convenience of the lecture presentation for the lecturer, but is unlikely to improve its effectiveness for the student! Unfortunately it is the obsessive commitment to lecturing that restricts the more extensive use of ICT as a learning vehicle. University academics do, of course, use their computers for email communication, searching for material on the web, the preparation of material for students and learned publications, recording research data, submitting student results and numerous other tasks. But ICT is also a tool that can be used to transform engineering education, rather than just be a tool to facilitate the delivery of our current inefficient educational strategies and practices! [69]

The ICT revolution that we are currently experiencing is still in a development stage. In the near future it will enable the information that students require, to be delivered electronically via the web into the student's personal library on their portable computer or tablet. The textbooks and journals which the students require are already becoming available for delivery in this manner. It will be their activity centre for reference material, assignments, projects, interaction, communication, questions and assistance. The availability of services such as Dropbox and iCloud is the start of this revolution of information anywhere and everywhere.

These developments will further emphasise that the role of education is to develop the student's ability to find, understand, evaluate and apply the information that surrounds them (and is a competency quite independent of the lecturer's ability to disseminate information).They will inevitably accelerate the demise of the current lecture model and move education to a learner centred model where the academic's role becomes the facilitation of learning through the creation of thinking experiences and the development of understanding. ICT provides an irrepressible mechanism to facilitate the transformation which is required in engineering education.

While students currently entering universities are quite competent with ICT, the future generations of students will be increasingly competent ICT users who will **demand** that the traditional universities also use these technologies, or they will migrate to the more flexible open or on-line universities. Some of the on-line universities have already grown to become mega-universities, e.g. Phoenix University in the US. They are able to provide lower cost education that is learner-centred while removing the constraint of student location and permitting flexibility in time commitments which may be required as a consequence of the student's part-time employment commitment, which may be essential for self-support. Future students will also increasingly be educated in schools that utilise student centred learning environments that encourage both independent and group learning, have less formal structure, with many teachers facilitating the learning of large groups of students and intensely dependent upon computer systems for the presentation and delivery of learning materials. Students entering universities can be expected to be increasingly proficient at finding, utilising and presenting material using an information technology environment and will also expect the physical facilities and processes of the universities to change from their traditional form.

ICT has also provided our education systems with a highly effective communication network for student-student and student-staff interaction. Student-student interaction can be a great facilitator of learning. They can share resources and experiences while mutually assisting their development of understanding as a consequence of this interaction. Additionally they need not be constrained by institution or country. Networking is a normal part of their life. It is also increasingly how engineers operate. Interaction has a particularly useful role in facilitating project based learning. Students may also share their information sources or knowledge to benefit the learning experience of others. The development of the essential graduate attributes can be efficiently promoted through the use of ICT.

Another important issue which needs to be considered in relation to ICT is that it enables the student to search for the material, information and understanding that they require, by accessing the extensive engineering learning material that is already accessible on the web. [70] This provides another way to create student centred learning experiences that can be an effective replacement for the role of the lecture. This has the capability to deliver a significant transformation of engineering education and it can happen now, as discussed in Section 5.8.

The age when the university was the dominant source of knowledge and information is past. They may be at the forefront of a discipline in a small number of areas, but information is now in the public domain and is readily accessible. The educational role of universities has become the facilitation of the development of students through an appropriate set of learning experiences, which enable them to develop the attributes necessary to enter their chosen profession. If a university views itself as just an information provider and a place for staff to communicate to students, it will face increasing competition from cheaper distance education providers that can utilise the communication capacity available to enable students to access the extensive information sources available more conveniently and effectively. A campus-based university must provide additional value for students or it will lose students to e-universities. However, they must also effectively use the technology to implement planned educational experiences that will motivate students to think and understand, thereby providing identifiable benefits to facilitate their development. It is difficult to envisage an effective engineering education program without every student having unrestricted access to a networked computer. For example ICT is indispensible in the Project Based Learning experiences discussed in Section 5.2.

The impact of ICT is now so pervasive that the digital generation will demand interactive, collaborative, non-linear learning experiences and faculty will be required to become designers of learning experiences, motivators of active learning, facilitators of learning development, and assessors of their student's realisation of the specified graduate attributes and capabilities.

Another dimension of ICT, which can have a major impact on program design, relates to the provision of student access to some of the software tools that are available to support engineering practice. As the objective is to have students learn how to operate as responsible and informed engineers, the environment in which they are educated should resemble that of an engineering enterprise. This suggests that the relevant software tools should be available to the students so that they can learn of their scope, capabilities, value, purpose, limitations and application. The use of this software in engineering practice is now so significant and widespread, that students should have the ability to utilise some typical packages, while also being aware of the range of packages available for analysis, modelling, simulation, design and implementation of engineering projects. The existence of this comprehensive software, that spans all engineering activity, also implies that while mathematical comprehension is important for all engineers, not all students require the depth of detailed mathematical expertise that was previously considered essential. This topic is further addressed in Section 6.3.

5.6 Student e-Portfolios

The Queensland University of Technology has successfully introduced e-portfolios as a useful application of ICT to support students [71]. Students are given the facility to develop their individual portfolio to help them:

- Create a plan for their study
- Articulate their objectives
- Collect and reflect on work completed
- Enter academic, personal and professional information
- Produce a dynamic resume
- Showcase achievements with examples

They can choose which content they wish to make public at any particular occasion. It is an attractive way to develop an effective CV for employment purposes. They may also choose to discuss sections with their academic advisor from time to time. In a student-centred learning environment this tool has considerable benefit as students can consider their learning experiences, evaluate their progress and plan what they need to do as a consequence. This should lead to interaction and discussion with their facilitator and lead to an agreed plan for the realisation of their next objectives.

The concept of it as a student controlled space, from which particular items only can be made available as they choose for any other party, is excellent. The student's results could be sent directly to their private site. As they consider and plan their progress towards their goals, there could be provision to regularly discuss their progress towards the development of each of the engineering graduate attributes, with their academic advisor/learning facilitator. Using this approach each semester to enhance student directed learning, could be an excellent tool to extend encouragement, understanding, motivation and support.

5.7 Learning Communities

The concept of learning communities is of fundamental importance to engineering education. It has been applied in a number of diverse ways. One form of learning community involves selecting students with similar interests, attributes and capabilities to be a group with a higher probability of being inclined to communicate well and which, through shared interests, will cooperate to enrich the learning experience for all in the group. They may also be a group working on a shared project, a tutorial group or a self-selected group who wish to interact.

Another situation is a group of distance-based learners who form a community of learners that interact electronically. The key principle is that students learn a great deal through their interaction with one another. It is even probable that they learn more from each other than from the academic staff. The role for staff is to ensure that learning communities are established and that they facilitate their operation and provide assistance as required.

There are a range of useful online tools to support collaboration, such as a Facebook group for asynchronous chat, Dropbox or Google Docs for sharing files or wikis for a more structured approach to sharing and building content. Most Leaning Management Systems offer these features, though students often find the free tools more appealing.

The responsibility of the staff is to define and facilitate the learning experiences for the students that are consistent with the objectives of the course, and can be realised through the use of identified or available resources. This involves creating an environment which questions and tests the student's thinking to enable the creation of understanding. Student interaction and sharing, to assist and extend one another with staff encouragement and facilitation, is the form of learning community that should be established. It can also be advantageous to occasionally invite senior students and experienced engineers to act as facilitators of the learning community's activities or, when invited, to provide insight and to broaden the community's perspective. Such a learning community can also beneficially embrace distance mode students, or students in another country, when they are sharing a relevant activity or objective. Raising our focus to establish such learning communities assists all of its members to progress toward the specified goals, and is to be preferred to a culture of individual advantage and competition.

If we let our imagination run a little, it is evident that this type of learning community requires a home room that becomes the location for individual work, interaction, searching for and accessing information, in addition to discussing issues with staff or mentor facilitators. It can be the environment in which project based learning is also located, and with appropriate IT facilities can be the location for student-centred learning activities. It should have the resources, tools and culture of an engineering office. The creation of an environment in which the students are:

- active participants in the learning experiences that are undertaken,
- responsible to ensure that learning is an enjoyable experience,
- inclusive of each other in learning activities,
- encouraged to communicate effectively with, and
- seek assistance from, the learning facilitator,

produces effective learning with outstanding student outcomes [72].

One of the authors (DGB) has been involved in establishing this type of educational model in a new International University that operates in Vietnam [73]. (Its range of programs does not, however, currently include undergraduate engineering.) There are no lectures and the students receive all their course materials electronically at the commencement of each semester program, in English, from the parent university in Australia. The students are responsible for their learning, while the staff members are responsible for the facilitation of their learning. The students accept this responsibility, and opportunity, with enthusiasm and utilise the facilities and assistance available to develop their skills and understanding. Each home room accommodates 50 students with computers. It is supported by a tutorial room for 25 students (where there are 3 hours of tutorials/week/course), a break-out (project or meeting or discussion) room for 6 and another for 12 students. The students enjoy this student-centred approach to education and perform outstandingly when assessed to the same standards that are used in the parent university, which continues to use conventional educational strategies. It is far easier to introduce a student-centred learning model in a new university, than to change an established one, as also evidenced by the following example!

The Singapore University of Technology and Design [18] is to accept its first student intake in 2012. It has enunciated plans for its engineering education programs that have many exemplary features. It has been established "to advance knowledge and nurture technically grounded leaders and innovators to serve societal needs". Its "curriculum is predicated on the belief that design is the key for future innovation" and its mission is to be "accomplished through an integrated multi-disciplinary curriculum" to be delivered through "cohort-based active and collaborative learning". Cohorts of 50 have a classroom which will allow students to form work and study groups flexibly and to utilise its educational technology facilities. Instructors, working in teams of three, are to provide assistance to students as they circulate around the small groups of this learning community. This university has also established formal collaboration agreements with MIT and Zhejang University to provide an international perspective to its graduates.

5.8 Web-Based Teaching Resources

Another development of very significant potential value for universities is the growing quantity of engineering educational material that is available on various web-sites. The most comprehensive is Engineering Pathway [70] which provides predominantly free access to teaching and learning resources in engineering, applied science, mathematics, computer science, information technology and engineering technology. It was created in 2005 by the merger of NEEDS [74] and Teach Engineering [75] and is a subset of the National Science Digital Library. The US National Science Foundation has been a key sponsor and, supported by industry sponsors and 8 major universities, was the initiator and enabler of this development. The searchable digital library covers all levels from K-12 to higher education (K-GRAY) and has quality control and review protocols applied to its content. The K-12 component seeks to provide an integrated STEM approach to assist the preparation of students for engineering programs. The philosophy of NEEDS, whose site [74] continues to operate, is conveyed by their perspective that "the new digital library of the future will be a community of learners, encompassing faculty, students and life-long learners".

The website contains over 13,000 educational items relating to engineering. Many of these items present a course (subject or unit) and may contain material addressing many topics which are each equivalent in coverage to a typical lecture. The required materials are selected from extensive menus for downloading. They are of interest to academic staff for course design and delivery and for students who wish to access new material and concepts, or who are seeking to improve their understanding of topics that have already been considered. Most of the materials are free (unless stated otherwise) and provided under fair-use policies which require acknowledgement (citation) of source material that is quoted. The resource is constantly being extended and welcomes the submission of items reflecting good teaching and learning strategies. It is a comprehensive and valuable resource that can be used for individual or team based student-centred learning and justifies far greater utilisation than it currently achieves. While the site provides information, as do textbooks and lectures, the presentations are often accompanied by interactive calculations or simulations which enhance understanding and learning as a result of their effective dynamic visual impact.

The ability to individually interact with the presentations can assist learning.

It would appear to be desirable for all engineering academics to be well informed of what is available in their discipline area, in this and other digital libraries, so that students can be directed to them as may be required when they need a supplementary source of material, even if they are not used as a primary source of information. A list of educational resource websites (including engineering) was created in 2005 [76]. NAE also provides information about resources for engineering education practitioners [77]. The availability of e-resources is further discussed in Section 8.4.

Another major resource is MIT's Open Course Ware site [78] where the curricula of most courses are accompanied by lecture videos, assignments and problems. This resource (nearly 2100 courses), provided to assist engineering education globally, is also a practical demonstration of leadership by MIT, through the total visibility of its educational offerings. A number of other universities are contributing detailed course content to the Engineering Pathway site, or other similar sites, to facilitate access-on-demand for their students, to market their Institute's strengths, to facilitate distance mode education and to facilitate reuse and collaboration between students and universities. The provision of learning resources in digital libraries will increase as the advantages of such material in supporting on-demand student learning, become more widely recognised. The advantages can be realised in terms of the enhanced learning effectiveness and its attraction to students. Importantly it can also assist by providing operational economies for engineering education providers.

There has been a recent development (December 2011) with the announcement [79] of a new online initiative by MIT. It has launched MITx which "will offer a portfolio of MIT courses on an online interactive learning portfolio that will:

- organise and present course material to enable students to learn at their own pace,
- feature interactivity, online laboratories and student-to-student communication,
- allow for the individual assessment of any student's work and allow students who demonstrate mastery of subjects to earn certification of completion awarded by MITx,
- operate as an open source, scalable software infrastructure in order to ensure that it is continuously improving and readily available to other educational institutions."

While seeking to enhance the learning experience of its on campus students it is also making a major contribution towards assisting the transformation of engineering education in other educational institutions through the provision of e-learning material.

Open websites devoted to engineering education are likely to expand rapidly. Such a site is GlobalHUB [80], which has been initiated by Purdue University with the support of the NSF.

It is now possible to identify that:

The sixth step towards Transformation is the utilisation of the wide range of Information Technology and Communication systems and resources to facilitate student-centred learning.

This step has numerous dimensions and while including the utilisation of the many approaches that have been described, there are many other possibilities that are only limited by our imagination as the access to ICT technology and its resources continues to expand.

5.9 Integrated Work Experience

The objective of incorporating work experience into an engineering degree program is widely accepted as a worthy direction, but its application has proved to be quite difficult in practice. It has been successfully utilised when the appropriate opportunities have been available and utilised. The purpose is to create an understanding of what engineers do, to improve motivation and to provide a context and relevance for the more formal learning experiences provided by the universities. The many alternatives that are used include:

- Gap year, which provides a year of work experience before the education program starts. In the UK there is an interesting program where engineering employers offer a one year orientation employment to intending engineering students in which they guarantee that the student will be involved in a challenging and exciting experience [81]. The objective is to attract students into engineering as well as to improve their probability of success through the motivation and understanding of engineering that they acquire.

- Sandwich Course, in which work experience periods alternate with study periods. There are many variations in format of such programs, but they have declined in number as a consequence of organisational and logistical difficulties. Employers tend to be supportive in principle, particularly if they are regularly acquiring new graduates, as it enables them to identify excellent potential employees while reducing exposure to the risk of misjudgements.

- Vacation employment: This provides an attractive option for students seeking to gain experience while evaluating potential employers and providing earnings to support their studies. However it would be more satisfactory if a little longer in duration.

- Integrated semesters of work experience. If universities utilised a three semester per year system, to better utilise their staff and facilities, then some of the additional semesters can be utilised for work experience without extending the length of the program. [73]

- Visits to engineering organisations and talks by practitioners about the projects they are undertaking provide some insight into the nature of engineering projects and the role of engineers.

- Focussing the student design/development projects upon the current physical requirement of a particular commercial organisation, and its fulfilment using the company's systems and facilities (e.g. fabrication, components, quality control, safety standards, project management, purchasing and record systems) can be a very effective experience for senior students. [82]

- If the home-room concept (explained in Section 5.7) is used for the learning community, then it should look, feel and operate as an engineering office with some of the facilitators being practicing or retired senior engineers who can provide insight of experience and stimulate students through their questions, suggestions and interaction. This approach requires the commitment of employers to participate and thereby create a real partnership with the university which can be of mutual benefit. Professional engineering facilitators could have a very valuable and effective interaction with project based learning teams bringing the reality of engineering perspectives and approaches to the students. The commitment may only need to be 1 hour/ week for each of a number of professionals as facilitators, but it would help to address the limited experience of most engineering academics as practising professional engineers.

5.10 Laboratory Programs

Laboratory experiences have been one of the strengths of engineering education programs as they provide a window to reality, while stimulating interest and motivation. They have many possible functions which include:

- providing a motivational link to practical engineering through establishing understanding of how equipment operates,
- giving insight into how some of the solutions to technical design problems have been achieved,
- providing an environment for experimentation and evaluation of various approaches to problem solving,
- establishing experience in measuring, quantifying and evaluating the performance of a technical system,
- consideration of the variation between theoretical performance predictions and actual performance,
- providing challenges to identify and solve problems,
- encouraging creativity,
- giving experience with embedded computer hardware for control, monitoring and data acquisition,
- providing the capability for the development, construction, testing and evaluation, of project designs.

However there are many reports of students finding laboratory experiments boring and uninteresting. Laboratories can become routine and ritualistic. They require investment and imagination to provide experiences that provide interest, and challenge the students, by providing learning experiences that reflect the role of engineers and assist in the development of the professional characteristics specified in the required graduate attributes. In engineering practice, laboratories are the place where engineering designs are explored, trialled, evaluated and if necessary redesigned until the performance required is achieved. Universities should also use laboratories with this paradigm (rather than for taking routine measurements upon a particular piece of equipment) to obtain the maximum benefit from the laboratory experience. The pervasiveness of digital controllers and data acquisition systems necessitates that all students need to obtain understanding of, familiarity with and confidence to utilise, digital systems and digital design tools.

The cost of updating laboratory facilities and the constraints of limited access times, have caused a number of academic groups to explore other options. Simulations provide one approach which can provide insight into some physical systems, but it has the limitation of using a theoretical model. The concept of Remote Laboratories providing virtual access to remote physical experimental facilities has delivered some worthwhile advances that are discussed in the Contributed Panel authored by Professor David Lowe.

Laboratory programs need to be reassessed and redesigned as part of the implementation of an effective transformation of engineering education. Relating the laboratory to the Project Based Learning component of the program (Section 5.2) would be the most effective approach. Appropriate design tools should also be available for use when they are relevant and essential. Fabrication workshops would be necessary to provide the physical realisation of the proposed design solution.

Another approach for the component of laboratory experiences that relates to the understanding of concepts and principles, is to provide for these activities to be undertaken in the engineering home-room of the students referred to in Section 5.6 and 5.9. This approach was pioneered by Rensselaer Polytechnic Institute (RPI) approximately twenty years ago when it combined the lecture and laboratory components of the preparatory technical subjects in a Studio Model [83] strategy. The outcome was greater efficiency of staff time, as the Studio group was approximately 50 students, in addition to improved learning outcomes. It also led to an efficient distance education model that was 80% self-paced engagement with on-line materials and 20% interactive synchronous learning with the instructor and other students [84]. The Studios were designed to facilitate laboratory experiments in the flexible open-learning space [85] and were constructed by converting existing teaching space.

Contributed Panel No. 12:

Remote Laboratories: Enriched Experimentation and Shared Facilities

Professor David Lowe

University of Technology, Sydney

The use of laboratory-based experimentation has long been considered a crucial educational tool in the applied sciences and engineering. Despite this, there has been surprisingly little consideration given to why and how laboratories are utilised. In educational settings often the intended learning outcomes for students from laboratory experiences are only superficially described. An ABET Colloquy in 2002 (Feisel et al., 2002; Feisel & Rosa, 2005) described a core set of thirteen objectives for Engineering laboratories. These related to the development of abilities such as applying appropriate instrumentation and tools, identifying the strengths and limitations of theoretical models, and the ability to collect, analyse, and interpret data, as well as many others.

One of the few areas where laboratories are being actively investigated is with remote laboratory access. In response to the emergence of sophisticated networked

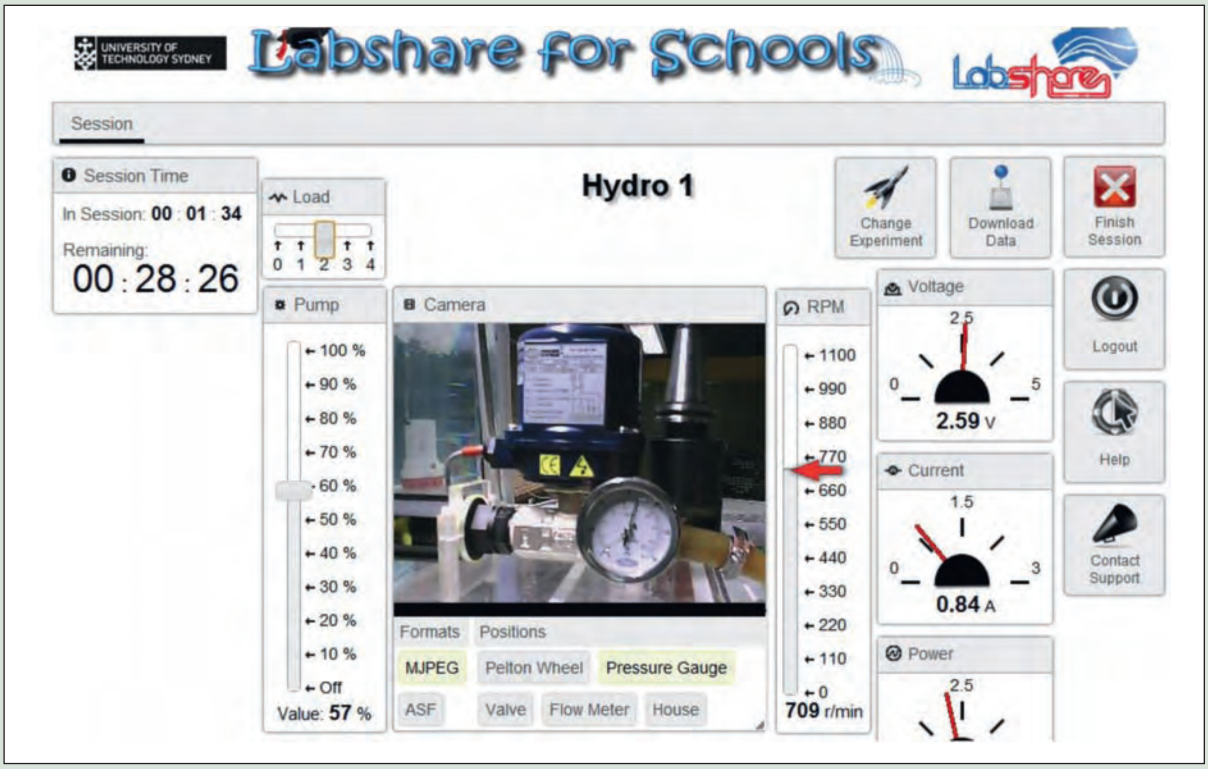

Figure1: Example remotely accessible laboratory – the UTS Hydro-electric Rig.

ICT infrastructure (and particularly the Web) increasing consideration began to be given during the 1990's to the possibility of remote access to physical laboratory apparatus. Since then there has been a rapidly growing interest in this area – as evidenced not only by the growing number and diversity of remote laboratory implementations, but also by the growing body of research in this area.

Traditional engineering teaching laboratories require students to be physically present in order to interact with equipment, limiting student flexibility, the type of labs that can be supported, and sharing of facilities. Conversely, remote laboratories allow students to use the internet to remotely access, in real-time, physical laboratory equipment. The interaction is supported by using sensors and cameras so that the student can monitor the laboratory equipment and actuators so that the equipment can be controlled. Students are still carrying out experiments using real equipment, but with much greater flexibility – the access can occur from anywhere and anytime.

The specific form of the remote laboratory can vary significantly. A remote lab might involve passively collecting data from a remote system so that the data can be analysed, or it may involve interactively controlling the system in order to trigger responses. The lab may be located within a teaching laboratory setting, or it may be embedded *in situ* within an industrial context (consider, for example, the implications of students collecting live data from a set of strain gauges attached to a road bridge). The experiment may be interactive, where the user directly interacts with the equipment whilst the experiment is being carried out, or it may be a batch experiment where the user sets up the experimental parameters and submits these to the lab system to be carried out when the equipment is available, with the results being collected once the batch run is completed. The supporting lab access systems that have been created also have increasingly sophisticated functionality – supporting functionality such as queuing for access, making equipment bookings, automated monitoring and reporting of the equipment status, etc. Figure 1 illustrates a typical remotely accessible laboratory developed at the University of Technology, Sydney using the Sahara system created as part of the Labshare project.

The depth of research and development related to remote laboratories can be seen in both the published literature and the implemented systems that have been developed. There is an annual conference series (REV: Remote Instrumentation and Virtual Engineering) that predominantly focuses on remote laboratories. Significant journal publications are regularly appearing in both specialised journals (e.g. The International Journal of Online Engineering) and mainstream Engineering Educational journals (The IEEE Transactions on Engineering Education, The European Journal of Engineering Education, etc.). Over the last 15 years there has been over 400 peer refereed publications that address remote laboratory issues!

The earliest era of remote laboratory research saw most effort being directed at technical evolution. Preoccupations included physical adaptation of the experimental apparatus to allow remote monitoring and control, technologies for real-time audio and video streaming, and dealing with the arbitration of multiple simultaneous requests for access to shared equipment. To a significant extent, many of these issues have been successfully overcome. Continuous, reliable and high quality remote access to labs has been maintained for much of the past decade.

In parallel with the progressive improvements in technical systems there has been an increasing interest in considering pedagogic issues associated with the use of remote laboratories. The technical ability to create remote labs is not really in question, nor is the potential they create for the sharing of access and improvements in flexibility for users. A very common question, however, is whether or not they are actually all that effective, particularly in terms of the educational outcomes that are being sought. Early work in this area tended to focus on comparing different types of lab access – particularly hands-on (sometimes called proximal) laboratories, remote laboratories, and simulations. The results of this early research were somewhat mixed. On the one hand, aggregated evaluations of student learning indicated that there is no significant difference between the educational outcomes from students who performed an experiment remotely, versus those who carried out a hands-on experiment (Imbrie & Raghaven, 2005). Such findings are similar in orientation to the majority of research in web based learning (WBL) which has focused on WBL effectiveness compared with traditional classroom learning.

More detailed studies have however have shown that, whilst overall learning is still achieved, students' performances on different criteria can vary depending upon the form of access used and that indeed some outcomes appear to be enhanced by non-hands-on access modes, whilst others seem to be degraded (Lindsay & Good, 2005; Taradi, Taradi, Radic, & Pokrajac, 2005). The overall conclusion from the research is that remote laboratories can, if used appropriately in a way *that takes into account the intended educational outcomes of the laboratory experience*, provide significant benefits!

Finally, there has also been consideration of the ability of remote laboratories to provide logistical or resourcing benefits. Early discussions considered aspects such as security, reliability and convenience, and considered the extent to which operating costs can be reduced through savings in both physical space requirements and reductions in maintenance costs. Possibly more significantly there has also been considerable interest in the opportunities created for the sharing of laboratory infrastructure. Two significant initiatives in this area are Labshare (www.labshare.edu.au) and LiLa (www.library-of-labs.org). Of particular interest is the establishment of the Global Online Laboratory Consortium (GOLC – http://www.online-lab.org/). This is an international association which aims to encourage the development and sharing of remote laboratories, including the sharing of expertise and resources and the development of appropriate standards.

Fundamentally, remote laboratories provide a range of potential benefits:

- Flexibility of access: the ability to carry out lab exercises anytime, and from anywhere.
- Access to shared labs that otherwise may be unavailable due to cost, space, or development capability constraints.
- The removal of time constraints on lab access (often associated with physical access to labs), and hence the option to repeat a lab as many times as desired, to explore different aspects of a lab, or to clarify elements that were not understood during previous attempts.
- The possibility for enhanced perception of aspects of the laboratory, through the use of instrumentation that focuses the student's attention on relevant aspects.
- Improved quality of labs through the ability to pool development resources when labs are shared across multiple institutions.

Whilst remote laboratories have now reached the point where they are being used for mainstream engineering education, there is still significant further educational research that is being carried out. Examples of areas being actively investigated include support for multiple students collaborating in a remote laboratory (e.g. (Callaghan, Harkin, McColgan, McGinnity, & Maguire, 2007; Lowe, Mujkanovic, & Murray, 2010)), communication when using remote laboratories (e.g. (Scheucher, Bailey, Gütl, & Harward, 2009)), and integration of remote laboratories into learning management systems (e.g. (Gravier, Fayolle, Noyel, Leleve, & Benmohamed, 2006)).

Perhaps more interesting is research into the ability of remote laboratories to provide experiences that cannot be easily created (or possibly cannot be created at all) in a hands-on laboratory. Examples of these include the ability to augment the laboratory experience in some way, such as overlaying a live video feed of the experimental apparatus with a representation of some physical, but non-visible phenomenon (e.g. Dormido et al. (2008) augment a video feed of a 3-tank control system); embedding the laboratory into a real-world context, such as allowing students to collect data from load sensors and cameras attached to a physical road bridge as traffic crosses the bridge; and providing access to experimental situations that are not feasible in conventional hands-on labs, for reasons of safety, security or access (e.g. experimentation using radiation or dangerous chemicals).

Further Information

Over the last decade there has been over 400 peer reviewed publications that address remote laboratory issues. For more information the following general sources are worth looking at:

- The Labshare Institute http://www.labshare.edu.au/: *An Australian-based initiative to support cross-institutional sharing of laboratories. This includes a good illustrative catalogue of typical labs.*
- Global Online Laboratory Consortium http://www.online-lab.org/: *This is an international association that is focused on* "the creation of sharable, online experimental environments which increase the educational and scientific value of learning which may not be accessible, scalable or efficient through traditional methods".

- International Journal of Online Engineering http://www.online-journals.org/i-joe/: *This journal is largely dedicated to publishing research in the area of remote laboratories, and includes work dating back to 2005.*

- International Conference on Remote Engineering and Virtual Instrumentation http://www.rev-conference.org/: *This is the primary annual event for researchers in remote laboratories to get together and discuss their work.*

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5.11 Summary of the Principles that can Guide the Transformation of Engineering Education

From whichever direction that we consider engineering education, it is not possible to escape the conclusion that engineering education needs to be transformed. Major changes are required in both:

- curriculum structure and content, and
- program delivery and assessment.

Presenting this in an alternative manner, it can be concluded that engineering education programs require major changes: both in what is done, and how it is done. There are benefits to be gained from considering both what is done, and how it is done, together, as they interact.

While the implementation of the necessary transformation of engineering education will be a difficult challenge for universities, the foregoing consideration of issues has identified a number of key steps that should be taken to guide the design and implementation of an effective engineering curriculum. They were:

- The adoption of the Washington Accord Graduate Attributes as the goals of each engineering education program to be realised by every graduate.
- The design of the curriculum to maximise the development of the capabilities that are essential to operate as a professional engineer.
- The design and implementation of the first year of the engineering education program to maximise student motivation.
- The utilisation of Project Based Learning in each year of engineering education programs.
- The replacement of the information transmitting lecture in engineering education programs with activities that generate student centred learning through the active involvement of students which creates thinking aimed at the realisation of understanding.
- The utilisation of the wide range of Information Technology and Communication systems and resources to facilitate student-centred learning.

Together they comprise Principles which can guide the realisation of the transformation of engineering education. Principles 1, 2 and 3 relate primarily to curriculum design while 4, 5 and 6 relate primarily to program presentation, although there are some cross relationships. The implications of following these principles are explored in detail in Section 6. They will lead to an engineering education experience which is very different from the majority of existing programs. It is accepted that university departments/schools/faculties will find them challenging to implement. However, we are facing serious calls for transformation that, in the interests of students, the profession and our communities, must be addressed. Major change is overdue. There are exciting approaches available and the implementation of change based on the realisation of these principles should be the focus of urgent deliberations. Section 6 suggests some possibilities to assist their implementation and hopefully it will provide a catalyst to stimulate more. The realisation of these principles can create the effective and exciting engineering education that our students require and our communities deserve.

6. Curriculum Design and Realisation

The Curriculum is the tangible plan for the content necessary to develop the desired graduate capabilities and attributes to be addressed during the students program of learning at the university. Currently it is disaggregated into packages (courses, subjects, units) to be delivered and controlled by individual academics. Each of these packages will have discrete objectives which are to be the focus of assessment. Individual courses are seen, quite correctly, as important by the academic staff, and unfortunately, they may become “protected domains” resistant to change. It is only at times of the commencement of new programs, or of major reviews, that the aims and objectives of the whole program are revisited.

With the requirement for a transformation of engineering education being so strong, it is important that the leaders of existing programs are encouraged and supported to revisit the design of their curriculum to optimise their student’s learning experiences. The current practices and strategies are not providing the outcomes that the engineering profession needs. Program leaders should be required and assisted to take responsibility to address and implement the changes that are essential to develop the engineers of the future with the capabilities that they require. However, little will be achieved without their understanding of the need for transformation and their commitment to its realisation. They need to be given the responsibility, held accountable for its implementation, and rewarded for its achievement. It is acknowledged that this is not a simple task so they will need to assist their staff and their institutions to take this journey with them [86].

Committing to the above six key principles would lead to a significant transformation, but there are also a number of other important issues that need to be considered and these will be addressed in the following sub-sections. The design and delivery of an effective Engineering Curriculum is a multi-variable complex system engineering problem. It does not have a unique solution, but it does have some essential elements, some exciting possibilities and, for most universities, promises much scope for improvement when the considerable challenges facing its implementation are addressed.

Engineering education programs vary in duration from 3 to 5 years depending on the entry standards and the nature of the program. They are more likely to require 4 years to reach graduate engineer standard. To focus considerations, only a 4 year program option will be considered. The principles can be readily applied to other circumstances. Another issue for curriculum designers is whether there are to be any advanced entry options; for example some Associate Degree (two year) qualifications may grant entry to year 3 of an engineering degree program. There may also be provision for an exit route to Engineering Associate or Technologist (a three year qualification). These options do introduce some constraints and will not be specifically explored, other than to say that these programs may require some consequential changes, or modifications made to the bridging program, to accommodate a transformed professional engineering program.

6.1 Program Philosophy

The graduate attributes required to be demonstrated by each student upon program completion should be a major determinant of the course philosophy, content and student experiences. They become the objectives of an outcomes based education (Section 3.5). The Washington Accord attributes (Section 3.1), which are a de facto international standard, deliberately emphasise the professional and personal attributes which must be developed by intending engineers. As has been noted already, existing programs are strongly criticised for being overly focussed on narrow technical detail and specialisation. The technical content should not drive the program design. The experiences necessary to create an effective engineer should be the key determinants of the program [87]. The approach of Purdue University to address the transformation of engineering education as a holistic problem which requires attention to the many details, by developing a strategic plan to guide its realisation, provides an exemplary approach [88].

It is suggested that engineering students should be treated as trainee engineers and confront engineering issues from day one of their program (just as medical students are treated like medical doctors in training from the commencement of their PBL programs). This can be facilitated if they are located in an environment that simulates an engineering office, where they are expected to operate like trainee engineers. They are then given tasks to acquire information about problems to be investigated; they work in teams, they have access to senior engineers to assist when they need guidance, they are able to access information sources, they can utilise facilities appropriate to their allocated activities and they are required to report the results of their projects to their supervisor and their fellow trainees. The objectives of the initial component of the program are to provide insight into what engineers do, to provide motivation (Section 4.7) through the consideration of some of the issues that are of interest and relevance (e.g. environment, sustainability, transport, energy, water, health, entertainment, infrastructure, national and international development, social impact, robotics, communication, information technology, etc.) and to commence the formation of the engineering attributes. The project based learning strategy (Section 5.2) should be inclusive of all students, male and female, and facilitate cooperative learning in the group.

Team projects are an ideal vehicle to provide the core of an engineering education program. They are able to develop an understanding of what engineers do, to motivate students to be committed to perform because the projects are interesting, and to facilitate the development of the desired engineering attributes and capabilities. They also serve to provide a vehicle for the creation of a base of general engineering knowledge and perspective, before the commencement of a chosen specialisation in a particular discipline of engineering. They provide a reason to access and learn about the various subjects, topics and principles that are relevant to their projects.

The concept of making engineering projects the core of the learning experience has been successfully demonstrated at a number of universities [48-49, 89-90], and enables the focus to be placed on the objective of becoming an engineer rather than to have this delayed until a foundation of science and mathematics has been created. These universities have a project based component in each year of the program, with the project component ranging up to 50%. Inclusion of Engineering Projects in each year, forming at least 25% of the program, would be a key decision if program transformation is to be achieved in our universities. In the advanced years of the program the projects would become more specialised, challenge innovation, and encapsulate the features of the capstone design projects which are commonly a strong feature of existing engineering education programs. In summary, engineering projects are the vehicle to:

- introduce a breadth of engineering understanding in early years,
- develop motivation and commitment to engineering,
- develop teamwork and leadership abilities,
- develop communication skills,
- introduce ethical, social responsibility and business dimensions of engineering,
- address the sustainability of all engineering projects,
- require innovation in the realisation of solutions,
- develop specialised knowledge in capstone projects.

An engineer must have the capability to understand the science and mathematics that underpins the field of engineering in which they will specialise. While this is not disputed, there is evidence that the over-emphasis on mathematics and science at the beginning of engineering courses de-motivates students with the consequence of a high drop-out rate and a diminution in the supply of graduate engineers and a reduced emphasis upon the development of the engineering graduate attributes. It constrains the development of the engineering components of the program by postponing engineering thinking and the development of the engineering capabilities. Programs that are developing engineers should have an engineering focus from the beginning and not consist of technology added onto a science core. This is a very clear message of the many voices requesting a transformation of engineering education. The question: "How should the science and mathematics components be addressed?" in program design and delivery is considered in Sections 6.3 & 6.4 respectively.

Another key question in relation to program philosophy is: "How is it possible to design an engineering education program that delivers student centred learning?" The strongly student centred component of current engineering programs is the design project undertaken by students at the end of their programs. The experiences associated with such projects develop initiative and other important individual attributes, integrate learning across topics, and are typical of a realistic engineering problem. Such experiential design projects should continue to be encouraged and comprise a component of the Engineering Projects stream proposed as noted previously. An Engineering Projects stream can provide a pivotal focus for student centred learning throughout the entire program as they provide a reason and incentive to pursue an understanding of the knowledge which must be acquired to address the questions raised in undertaking the project. The creation of an incentive to learn is a key to achieving effective learning. It does not appear that there is a more appropriate or convenient vehicle to stimulate student centred learning than project based learning. However PBL does not automatically create student-centred learning. Other actions must be implemented to achieve this as noted in Section 5.

Another form of project that has been successfully used at a number of universities is to utilise actual projects which may be for a company or for the community. The latter, that have a strong social and possibly business requirement, can be most beneficial in broadening the student's perspectives. Purdue University has a well developed program titled EPICS, Engineering Projects in Community Service [91]. Also working upon an actual company project can have very realistic constraints that create excellent learning experiences and encourage an interest in innovation.

The projects create an experience that develops broadly the student's capabilities (consistent with the desired graduate attributes) and an understanding of the necessity for them to acquire the knowledge required to undertake their responsibilities in the project team. They provide an opportunity to encourage the student's responsibility for their learning, rather than being dependent upon the all too common staff-centred lecture model. The students, with a need to acquire knowledge, can be encouraged to take responsibility for its acquisition using the available information sources. The student-centred learning model can involve acquiring the information that they seek from: prepared course notes, reference books, websites, e-learning material, learning exercises, libraries, magazines, tutorials, fellow students, experienced facilitators and/or team members. All of these can assist to deliver the student-centred learning, which has been given a coherence and purpose by the Engineering Projects stream.

It is not desirable or effective to build the program around a series of ineffective and, consequently inefficient, lecture presentations when the alternative exists to use a project-based program to create student-centred learning which is consistent with the development of the desired engineering graduate attributes.

This is the core issue.
It is the key to transformation.
It requires major change.

This represents a significant challenge to the engineering staff and their universities. It is not evident that there is an alternative approach which can achieve the necessary transformation of engineering education. It is, however, achievable with the commitment of academic staff, the engineering profession and employers. It has been achieved in a very limited number of exemplary universities. The need to expand the details of how this concept could operate is addressed in the following sections.

While the lecture based program remains the norm, engineering education will continue to require a transformation. The lecture method is widely used because it is the easiest method for the academic staff member. While it is designed to permit students to be exposed to the accumulated wisdom of the staff member, it often fails to effectively meet that aspiration. It allows the lecturer (academic staff member) to appear to be fulfilling their responsibility for assisting the student to learn, while they present (largely without interaction and often with little preparation) information that is available elsewhere. In reality the responsibility of the academic staff member to facilitate student learning has been abdicated when they continue to rely on the lecture method. Sections 5.2 and 5.3 provide relevant background to this topic.

To seriously promote student-centred learning a dedicated home room (Section 5.6), which provides an engineering project office-like environment, is required, as discussed above. This environment would include computers to search and obtain information, communication within the students learning community (wherever and whoever that is) and with staff, IT packages for design, computation, simulation and modelling, bench-top experiments, and project team work. Many universities are now providing this type of learning facility, but usually for casual student interaction within a department, school or faculty. This has occurred because libraries, the usual quiet student study and research location, are not readily able to provide sufficient interactive (noisy) spaces essential for student centred learning.

Additional home room spaces of this type will be required in universities and hopefully far fewer lecture theatres. Modifying and updating the physical facilities of the university to be suitable for an engineering studio approach rather than a lecture based model of education could involve a significant expense depending on the university's campus structure. Ideally a learning space of this type should enable the students to interact with each other as they endeavour to think through the issues that confront them as they undertake their projects, achieve understanding and thus learning.

Additionally someone with experience should be available for the incidental facilitation of the student's learning, to provide advice as to what some of the relevant issues could be, where information may be found, questions that could or should be asked, and also to provide assistance and review the student's thinking and progress when required. They do not need to know all the answers! They do need to be able to say that they don't know, be able to assist with identifying the issues to be addressed, identify students who may benefit from cooperating, know some of the questions that need to be asked, and to be able to guide students towards an approach that may be fruitful. The facilitator could be an academic staff member, a senior or post-graduate student, an experienced engineer from a local company or a retired engineer or preferably a mix of all, at different times. Additionally tutorials, driven by student questions, should be provided on a programmed schedule, to assist the student-centred learning process while achieving the desired coverage of the objectives of the particular learning module. The tutorials may need to be in various subject or discipline areas. Their objective should be the development of understanding, not the presentation of information.

A key objective of the team-based projects and the student-centred learning proposed is to encourage and assist the development of the attributes, capabilities, skills and experience that are essential in the formation of an engineer. Consequently projects should be chosen to require a wide range of differing considerations and not be limited to narrow technical problems. During the early years of their program they should also give the students insight into some different fields of engineering specialisation, assisting them to make an informed choice of the field in which they would wish to specialise. Academic staff, facilitators and cooperating engineering organisations will all be able to provide ideas for project topics, and additionally student suggestions of topics that they would like to explore, should be welcomed. Some projects may be run as competitions on a university, national or international basis.

The range of possibilities for the Engineering Projects that may be planned for the student teams to pursue is limitless. They should be graded in complexity and selected to cover a broad range of engineering topics or fields in the first two years, to assist the students to develop a breadth of technological/engineering understanding, while also facilitating their decision in relation to the discipline of engineering in which they would prefer to specialise. Project specialisation could be expected to commence in the third year of a program with this type of format. The objective is to develop a variety of skill sets and students should undertake a variety of roles within their groups. The projects can be of varying time duration, require teams of various size, have a company relationship, involve cooperation with other universities, be international problems, have community interest, be competitive, require innovation, have a commercial dimension and require different forms of presentation. The work of the teams should be presented in various formats as may be appropriate and shared with the other students.

6.2 Program Structure

Engineering education programs, while aiming to assist students to achieve each of the Washington Accord graduate attributes, should contain the elements necessary to provide the following:

- A motivational foundation.
- An engineering project stream that will incorporate broad system engineering projects which introduce students to the breadth of engineering activities, provide opportunities to develop the general engineering attributes, include team and individual projects, be based on project based learning principles, and include design projects.
- A broad knowledge of engineering and its technological fundamentals and principles.
- A familiarity with mathematical tools sufficient to understand engineering fundamentals and to obtain solutions to engineering problems.
- Knowledge of the scientific principles, theories and relationships which are necessary to understand the technological issues associated with engineering.
- The capability to utilise information technology effectively to obtain information and to communicate, compute, design, simulate and model, in relation to the development and implementation of engineering solutions and systems.
- The development of a detailed technological knowledge in a specific field of engineering, and the ability to utilise it to solve engineering problems creatively.
- Experiences that provide insight into the social, business, environmental, leadership, ethical and personal issues that are involved with working in an engineering project team.
- The development of communication and presentation skills in various situations.
- Development of the ability to be an independent life-long learner.

Consequently an engineering program must contain the following components:

- Project stream
- General engineering fundamentals
- Mathematics
- Sciences
- Information technology
- Engineering specialisation
- General educational experiences

and will preferably include a work experience component. A structure that is simple and allows these requirements to be met logically is:

Years 1 & 2:	Project Stream Engineering Principles/ Fundamentals Mathematics Sciences Information Technology
Years 3 & 4:	Project/Design Stream Engineering Specialisation General educational experiences Electives

The significant advantages of this program structure are that the objectives specified (the graduate attributes) can be developed and realised both coherently and efficiently. Coherently because it enables the broad motivational activities to be located at the beginning of the program within an activity framework that commences the development of the required attributes of an engineer in the students. Then, as they progressively achieve insight into the scope and complexity of engineering problems, they can strengthen their capability with the tools which they will need to utilise as they expand the depth of their knowledge and capability in their chosen discipline. It is also coherent because it provides the necessary breadth of engineering knowledge even if a student has already chosen their preferred discipline.

It is efficient because the first two years can be provided in a common program without compromising the program's objectives for each specialised discipline offered. It also allows students to delay their choice of specialisation until they have some appreciation of the various options and can resolve where their preference lies. Reducing the range of courses offered within an institution leads to many economies and efficiencies. Using student-centred learning can also be more economical than the lecture/tutorial model. Reducing the cost of engineering education programs is quite important as it is can be anticipated that the contributions to universities from the public funds are likely to decrease on a per student basis.

With a common first two years it is also possible to share educational resources between students in all universities, instead of each developing their own independently! A more achievable, and therefore more likely strategy, would be for collaboration between syndicates of universities. (CDIO has already created one.) Project ideas could be shared and excellent resources for student-based learning identified and added to appropriate web-sites. There is also the possibility of resources to support staff in their roles being shared on the web. Cross-university projects could also share their different approaches to the same project. There is no end of possibilities for benefits to be obtained from cross-institutional cooperation. Such collaboration could be undertaken without compromising each university's independence and responsibilities to deliver an appropriate education for its students as they would each have control of their own staff-student interaction, the learning experiences and the assessment processes.

Collaborating syndicates could have institutional members from various countries to demonstrate that projects require different approaches in different circumstances, introduce some international projects and the operation of international teams for some projects. The international exchange of students could be encouraged and the specialisations available to students could be expanded without all specialisations needing to be conducted in each university.

The third and fourth year provide the opportunity to develop the student's chosen technical specialisation. The specialisations available to them would be determined by the focus of the staff in each university. Two years of specialisation will allow considerable depth to be developed and again the learning processes would be given cohesion by the project stream where the projects would focus upon design and the realisation of solutions to increasingly specialised projects. The aim would be to continue the development of the engineering capabilities within this framework, with the support of relevant general educational experiences. The focus on student-centred learning should also continue.

6.3 Mathematics for Engineers

Mathematical ability is a core attribute of an engineer. It is a language in which they must achieve fluency and familiarity. However, addressing the mathematical component of engineering courses is difficult because of the considerable variations in the student's prior preparation as a consequence of their secondary school experiences. This is an extremely important issue because of its disproportionate contribution to the high failure rate and consequently the high dropout rate of engineering students. The need for an approach that provides streaming of students based on their ability at entry to the course has been long recognised [92], but is only occasionally implemented. A comprehensive coverage of the diverse issues related to the effective delivery of the mathematics requirements in engineering education programs is given in the Contributed Panel authored by Professor Tony Croft.

Additionally the Helping Engineers Learn Mathematics (HELM) program at Loughborough University [93] has developed 48 student Workbooks containing mathematical topics and related engineering exercises that can be utilised by individual students for the development of their essential mathematical skills. They allow the student to establish their current level of understanding in each topic and then to proceed to establish the required knowledge and capability. They are suitable for individual study, distance learning, in a tutor assisted mode or in a teacher-led situation. While they are freely available to UK universities they are also available to subscribing universities at a modest fee. This provides an excellent student-centred learning approach for the core mathematics component of engineering education programs for any university to utilise.

The use of computer programs to model or simulate the complex systems that engineers will inevitably meet in practice, should also be provided in association with the development of the student's mathematical experience and competence.

Contributed Panel No 13:

Addressing the Mathematical Requirements of Engineering Education Programs

Professor Tony Croft

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Having taught and supported engineering students with their learning of mathematics for around 25 years, in the first part of this article I give a personal perspective on the challenges faced by those who are charged with teaching mathematics to engineers. In the second part, I describe the development and contribution of mathematics support centres – one possible type of mathematics support for engineering students, and one that I have championed both at Loughborough University and much more widely.

Teaching mathematics to engineers – the challenges

The expectations upon those studying for engineering qualifications in higher education are demanding indeed. In addition to studying the engineering subject matter itself, there are the underlying scientific, physical and mechanical principles, and many of today's engineering students are expected to develop additionally skills in business, management, entrepreneurship, foreign languages, environmental impact assessment, green technologies and much more. Thus, whilst few would dispute that mathematics is the language in which engineering and scientific principles are expressed, we must recognise that, for engineering undergraduates, the study of mathematics is but one of many calls upon their time and effort.

Traditionally, engineering education has included courses in mathematics, probability and statistics: there has been widespread agreement about the need to cover core topics such as basic calculus, linear algebra, differential equations, numerical methods, probability distributions and basic statistical hypothesis testing. However, the extent and depth to which these (and additional) topics are covered is by no means uniform and depend upon the particular type of engineering course and the type of institution in which the student is studying. Staff at Loughborough University where I teach, have pioneered mathematics for engineers as a discipline, contributing via curriculum development, hosting regular international conferences on the mathematical education of engineers, and editing the *International Journal of Mathematical Education in Science & Technology*, since the 1960s beginning with the work of Bajpai, Mustoe, Walker and continuing with the many others who followed them. Over several decades the undergraduate curriculum and ways of delivering it have changed very little.

However, during the nineties and into this century there have been several developments that impact deeply and provide challenges for those charged with overseeing and delivering an appropriate mathematical curriculum for engineers. These developments include a widely recognised problem associated with the mathematical preparedness of incoming students for the demands of engineering courses. An early substantial report on the issue in the UK was that of Sutherland & Pozzi in 1995[1]. In 2000, the report *Measuring the Mathematics Problem*[2] was seminal in drawing the problem to the attention of policy makers and government. Much more recently *Newton's Mechanics – who needs it?*[3] highlighted the fact that the mathematics problem has a second dimension – not only were there too many students who had not developed skills sufficiently in mathematical techniques, there were many (more) others who had little or no knowledge of the basic Newtonian mechanics so essential for courses in mechanical engineering, physics and applied mathematics. The problem is not restricted to the UK – for example, the worsening situation in Australia is described by Henderson & Broadbridge.[4] In addition to this lack of preparedness there are other factors that exacerbate the situation. The dialogue between higher education and the school system in the UK is not as good as it could be, and work (by those in higher education) to recognise that students emerge from the school system with learning styles which are not always well-aligned with styles of university teaching and to better prepare themselves would be very beneficial. This requires investment, support and reward for those university teachers committed to delivering excellence. Good teaching of mathematics in schools in the UK (and in many other parts of the world) is hindered by ongoing shortages of good mathematics teachers,[5] and an unwillingness of many mathematics graduates to consider careers in school teaching. It also has to be recognised that social changes and the availability of superficially "more exciting' (and arguably less-demanding) undergraduate courses mean that an insufficient number of bright young people in many parts of the world choose to study engineering and related disciplines.[6] Meanwhile the pace of technological change has been great – today's students have access to information of unprecedented volume and speed. Computer software can solve almost instantly many of the mathematics problems that older academics and professional engineers struggled for hours or days with. Recognising the difficult challenges with teaching mathematics, and also the potential of new technology it is not surprising that there is disagreement in the academy about how much mathematics should be taught to engineers.[7]

Then there are also disagreements about which academics are best placed to teach mathematics to engineers. There has been a trend recently in the UK for many engineering departments to teach mathematics "in house" rather than to source engineering mathematics teaching as a "service" from a mathematics department. Sometimes, reasons for this are financial. Sometimes it may be because the mathematics department may be 'milking the cash cow' without providing its best teachers, and supporting the engineering students adequately. Sometimes it may be because those in the engineering departments believe that they are best placed to teach the mathematics required 'in context' and as and when it is needed. There is no consensus on the best approach, but there is a danger in the latter position. If mathematics is to be truly useful for engineers, then they need to learn to think about problems mathematically; they need to appreciate that mathematics is more than a tool for solving isolated problems in engineering (and this is the danger of teaching in-context, just-in-time). Rather, mathematics ought to be the ultimate transferable skill in that those who can think mathematically can apply their knowledge and thinking skills in diverse areas, bringing new insights, calling up rich and powerful tools for problems once they have been posed mathematically. Those engineers taught to think mathematically will be better-placed to meet head-on the *unknown* challenges of the decades ahead. At Loughborough University, we have established the Mathematics Education Centre (http://mec.lboro.ac.uk). One of its primary aims is to oversee the teaching of mathematics to engineers so that, as far as is possible, they do begin to think mathematically, and are very-well supported in their learning.

The challenge for us, engineers, mathematicians and mathematics educators, is to try to be creative in solving these problems – better support for students; better use of technology, development of appropriate curricula, and better liaison between the different stages of our educational systems to provide a seamless transition from school mathematics to that required in higher education.

Mathematics Support Centres – a positive response

In the second part of this article, I focus on *supporting* engineering students in their learning of mathematics. Many of these students struggle with the mathematical components of their course – many others do not, and want to understand well the mathematics they are learning. As with all of these things, there is more than one way to tackle a problem. Institutions must develop support that is appropriate for their students in their particular situation. An approach which I have championed since 1996, initially as a response to the 'mathematics problem' highlighted above, has been the support of engineers through **mathematics learning support centres.** The term 'mathematics support centre' is usually taken to mean a dedicated, physical space in which to offer mathematics support. The centre may be used to house a bank of learning resources so that students are encouraged to help themselves and not rely solely on the intervention of a tutor. Figure 1 shows part of one of the support centres at Loughborough University. Many centres offer students workspace to encourage learning communities, collaborative learning and peer support as shown in Figure 2. Tutors are available in the centre at specified times (Figure 3). There is often access to computing and other facilities such as video. There is some variation in where support centres are located: they may be in a mathematics, engineering (or other) department or in a central service such as a library or skills centre. There are pros and cons whichever location is used. Some centres may employ staff dedicated to offering mathematics support whereas others may make use of mathematics and statistics lecturers and postgraduate tutors.

Increasingly, support centres are the focus of related initiatives, for example offering diagnostic mathematics testing of new students, supporting students who have additional needs, and for preparing students for employers' selection tests. Many centres have successfully sought funding for other teaching and learning projects and so they can very usefully provide a focus for those staff who are interested in mathematics education more broadly.

Much has been written in the last decade or so about support centres and in 2003 Lawson et al published the guide *Good Practice in the Provision of Mathematics Support Centres*[8]. In the period up to 2004 there was a rapid growth in the number of centres. A thorough survey, carried out by Perkin & Croft[9], that showed that over 60% of UK universities had support centres. Since then many more UK centres have opened. Networks of mathematics support professionals have been established in Scotland and in different regions of England and Wales. In other parts of the world there has been rapid growth too. Surveys have been undertaken in Ireland[10] and in Australia[11]. A report by the UK National Audit Office in 2007[12] recommended that support should not be seen merely as 'remedial' but as a way of enhancing the quality and experience of even the best students.

With the widespread growth in support centres, there is a growing evidence base of evaluation studies[13]. An archive of known reports and papers can be found from the mathcentre site[14] (which incidentally offers hundreds of freely-available mathematics resources suitable for engineers). And now in 2011, it is true to say that mathematics support centres are part of the landscape of higher education. They assist in addressing such institution-wide priorities as retention, recruitment, quality enhancement, employability and skills, the first year experience, flexible delivery, inclusivity, support for postgraduate students, the national STEM agenda and the student learning experience.

Figure 1: Part of a mathematics support centre showing student workspace and resources.

Figure 2: The mathematics support centre encourages student collaborative learning.

Figure 3: A tutor offering statistics support within the Centre.

Looking to the future

So what is needed to address the mathematical requirements of engineering education programs?

- There is insufficient research, undertaken with an international perspective, about the true mathematical needs of the engineer of the future.
- There is insufficient research concerning the value of a good mathematical education not simply to provide tools for solving specific engineering problems but for much wider, high-level, transferable thinking and problem-solving skills and the value of *thinking mathematically.*
- We need to continue to recognise the "mathematics problem" and work hard to support those students already in the system. Such support needs to recognise both the diversity of mathematics within the engineering disciplines, and also the diversity of the student body – with many mathematically gifted undergraduates often being taught alongside those who are intimated by mathematics and who have little in the way of adequate preparation.
- Greater emphasis should be placed on encouraging higher education staff to improve the dialogue with school teachers and school students so that the curriculum and teaching styles are better aligned.
- There is insufficient knowledge about the value of technology in the teaching and learning of mathematics for engineers.
- There needs to be recognition and reward for those who want to work in the furtherance of the mathematical education of engineers so that they are motivated to seek solutions to the problems described in this article, and to champion better and more innovative teaching and better support for engineering students.
- the status of engineering as a profession needs to be enhanced so that more brighter students are attracted into it.
- The importance and value of mathematics to engineering needs to be made much more explicit through the publicising of its many modern applications in a form accessible to the general public.

Taken together, actions in support of these, would transform the mathematical education of engineering students. The challenges are not easy to grapple with – however I would argue that one of the skills our mathematical training purports to develop is the skill to tackle difficult problems! So let us put our own skills to the test!

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6.4 Science for Engineers

An understanding of the fundamental principles of science is a basic requirement for engineers. The science component of the first two years of the engineering curriculum should provide the interface between the student's prior knowledge and the coverage of engineering principles that is required for a broad engineering knowledge and for the consideration of the projects that are investigated in the core Project Stream. It is envisaged as being broadly based across physics, chemistry, materials and biology. There needs to be an appropriate syllabus that guides the scope and depth of understanding that is expected of the students and defines the scope of the summative assessment consistent with the specified graduate attributes of the program. However the course should be student-learning based with the students being directed to an appropriate selection of web-based learning materials, with learning being supported by tutorials as discussed in Sections 5.8 & 5.9.

6.5 Information Technology

The information technology component of the program does require some further comment. It should be addressed at the commencement of a program for a variety of reasons. Firstly, while many students will be well versed in the use of IT as a tool it is important that all students are familiar with, and confident users of, the IT systems that are provided for their use by the university to obtain information, communicate with the academic staff and fellow students, to create discussion or work groups, to use as work spaces, and to submit assignments. Protocols, privacy, security and ethics, also give the opportunity to explore and understand how IT systems operate at a variety of levels from programming to computer science to digital systems. Such information is critical as they will inevitably be utilising digital systems in their projects at an early stage. IT is one of the engineering principles that need to be mastered.

A further component of this learning module should be an introduction to the concept of student portfolios (Section 5.3). Also the creation of their personal library of learning resources on their personal IT device should be addressed. They should be introduced to the major websites for engineering education material and become efficient and responsible users. The student's familiarity and competence with IT tools will be critical to their success in the course and in engineering practice. Obviously expertise in this field will continue to develop quickly throughout their program.

Also a close relationship with the Project Stream is required to ensure that knowledge of the modelling and simulation software tools that may be required is provided at the appropriate time. Familiarity with the structure, limitations, application and utilisation of these packages is required.

6.6 Assessment

Assessment is a most important issue. It is a key responsibility of academic staff and universities. The certification of graduates as having met the requirements for graduation is relied upon by the community and the professions. Assessment is, of course, important for students and it impacts on their learning strategies. It also impacts on the effectiveness of the university's education programs. In view of its importance it is amazing how little attention is given to its validity, and its impact on the effectiveness of educational programs. Currently engineering education uses the same strategy for assessment as other programs in the university. Assessment policies are devised on the principle that a unit of teaching has considered a series of topics and that as a consequence students must be able to demonstrate: appropriate knowledge, an understanding or the development of a skill, as may be required. The current assessment infrastructure imposes, however, considerable constraints on the transformation of education in general and engineering education in particular.

The approach that is proposed for the transformation of engineering education necessitates some freedom from the constraints of current assessment policies of universities. Assessment remains the key mechanism in determining and maintaining standards and in achieving validation and accreditation [94]. But a transformation of engineering education programs must be matched by changed assessment processes [95].

The starting point for assessment should be that the objective of engineering education programs should be that the students must possess the Washington Accord graduate attributes upon graduation. Also the university must be expected to provide evidence that this has been achieved to the professional accrediting authority. The clear implication of this is that the achievement of each graduate attribute should be explicitly assessed. As noted previously the attributes are general statements of the capabilities expected of engineers. Such an assessment process would require each university to specify the standard that they require students to satisfy to demonstrate for their realisation of each graduate attribute (Refer to Section 3.5).

The graduate attributes vary in their nature. The achievement of knowledge and skill dependent attributes can be demonstrated through conventional objective assessment processes assuming that the assessment process is appropriately designed. Other attributes such as ethics, communication skills, responsibility and teamwork require subjective assessment. A different approach to their assessment is essential. Assessment of these attributes could use a formative assessment process that indicates to the student progressively, how their performance has been rated. Using as an example the attribute of teamwork, it is possible to have fellow team members rate themselves and each other on their contribution to team outcomes and to have the academic staff and facilitators also provide their assessment. The student could receive this feedback progressively throughout their program and use it constructively to improve their performance by addressing the areas of perceived deficiency. Their final result statement could show their performance against each attribute to guide employers of the relative strengths and weakness of the student across the profile of attributes, as well as showing the accreditation authorities that the development of these attributes has been seriously addressed and that the standards set by the university have been realised by each student.

There are other aspects relating to assessment that require comment. The assessment processes of universities are mostly summative. Assessment is often used as a device to cause work to be completed, to compel attendance and to compel completion of homework problems or assignments. Also It appears to be accepted that there will be a high failure rate of engineering students. It can be a point of pride for some academics that certain courses are very difficult, as if the objective is to cause a significant number of students to fail. Formative assessment should be predominant, to enable students to be assisted in their learning processes, in contrast to the current situation in which assessment is predominately summative. Continuous assessment can be used to deliver benefits for students as they receive valuable feedback and guidance as they proceed through the program.

The first year programs commonly have high failure rates that may even approach 40%. This would appear to be a matter for condemnation of the program design, delivery and assessment, rather than a student failure. The first year students may require a longer period to adapt to the different form and expectations of an engineering program and would benefit from a predominantly formative assessment paradigm. The project based learning model proposed in Sections 6.1 and 6.2 lends itself to more formative assessment and it may be appropriate to consider the benefits of delaying any summative assessment until the end of year 1, or even until the end of year 2, as there are appropriate incentives for the students to work diligently within the project based structure.

The use of the Students e-Portfolio (Section 5.6) as a tool to plan the students learning experiences in response to feedback from formative and summative assessment, and to record their achievements, is a recommended approach. It encourages students to see themselves on an individualised educational journey that will lead them through the development of the engineering attributes which are required by the accrediting authority. It also provides a mechanism to communicate to all stakeholders what a student knows, understands, has done and can do, as a result of undertaking their program.

6.7 Quality Management

Quality is often used as a descriptor to identify a product that has superior properties in comparison to its competitors. However it is usually an empirical concept as it is commonly based on claims rather than justification, and on emotion rather than evaluation against specified standards.

Quality in education, when used in a technical sense, is normally referring to “fitness for purpose”. For engineering education the purpose is clear: a high percentage of the students should be able to graduate while satisfying the Washington Accord graduate attributes. The process of ensuring quality (or quality management) is well understood in engineering. It involves having clear objectives, implementing activities that are intended to achieve the objectives, measuring the results of undertaking the particular activity, comparing the results achieved with the desired outcome and, if the results are not as required, taking corrective action to ensure that the desired result is achieved. It is nothing more than good management practice. However it is seldom applied effectively in universities or engineering faculties or departments. If an institution is seriously committed to the transformation of engineering education, then the implementation of quality management processes is essential.

While it is a simple process to describe, and it makes sense that it should be operating as a component of normal accountability and responsibility, why is it seldom implemented? The biggest problem to overcome is that of obtaining accurate performance measures. However if we have clear graduate attributes that must be achieved (the objectives), developed through appropriate pedagogy (the activities), and we are committed to the assessment of their achievement by every student (the results), then there is nothing to prevent the quality feedback loop being closed by careful consideration of why the results depart from the objectives and determining what actions can be taken to improve the results. The next issue is obtaining the confidence of the academic staff to permit this process to proceed as a constructive team focussed activity without any threat of victimisation.

Quality management is a responsibility that should be exercised within each university by the responsible Program Coordinator, with the assistance of the Course Coordinators. It is about measuring the actual performance of the program by measuring the student's achievements as a result of undertaking it, and implementing appropriate changes to critical process parameters to achieve continuous improvement towards the desired outcomes. Quality assurance is the process that should be conducted by the external Accrediting Authority. It entails the examination of the adequacy of the quality management processes undertaken by the university, the evidence of the performance achieved and of commitment to continuous improvement. Quality assurance is not possible if quality management processes are not operating.

Quality processes are critically dependent upon the accurate measurement of the outcomes achieved. They rely upon the accurate assessment of the achievement of the graduate attributes by the graduating students as discussed in Section 6.6. Unfortunately academic culture has not embraced open evaluation and hence, even the quality processes that have been implemented, are seldom adequate. Universities tend to assert quality on the basis of status, public image, student entrance grades, research performance, international rankings or government grants. None of these is an adequate indicator for program quality or the effectiveness of the educational experiences. Quality management, however, should be embraced as an essential component of the transformation of engineering education.

6.8 Collaboration: Local, National and International

There are a number of forums that exist to promote collaboration on issues relating to engineering education. They can be useful where there is a common interest, such as dealing with an Accreditation Authority, a Professional Organisation, a Research Grants Body, a Public Inquiry, an International Organisation or a Government. If there is funding for a shared activity, co-operation will be stimulated. However, when it comes to identifying examples of institutional collaboration aimed to enhance the effectiveness of engineering education, for the mutual benefit of the students and staff of a number of institutions, it is difficult to find many significant examples. CDIO (Section 4.6.5) may be the best example as there are shared objectives, although the collaboration dimension may be quite variable. While collaboration between individual academics can quite readily cross institutional and international boundaries, when they have a common interest, institutional competition often acts to prevent meaningful collaboration at an institutional level, even when agreements have been signed to support the intent. There are many examples of individuals collaborating across institutions on engineering education issues and projects, particularly on scholarly research.

There is significantly more collaboration between universities when the objective is to undertake technical engineering research projects, programs or centres as there is a need to establish teams of significant capacity and with an appropriate spread of expertise to win the support of funding authorities. Such collaboration is usually very fruitful as objectives can be readily aligned and the activities are consistent with the policy and objectives of each institution. There are also some excellent research grant schemes where the collaboration must be established between university researchers from two countries to enable a competitive grant to be awarded with funding from both countries. Australia, for a number of years, also had a successful program where funding for major research infrastructure was only provided when the universities in the particular field established a plan for shared use of the essential infrastructure, if that field was clearly of national significance [96].

Competition between universities for local students, for international students, for research students and for staff, acts to prevent collaboration between universities and even between departments and schools within the same university. However, if there is to be a transformation in engineering education, there is an opportunity and a need for collaboration to share the planning, ideas, concepts and experience to enable the improvement of engineering education for the benefit of the students, the universities, the employers, the profession, and the particular countries, while reducing the cost for the participating universities.

Collaboration on transforming engineering education by focussing the curriculum upon the development of the engineering capabilities, and changing the learning experience to be student focussed, could be mutually beneficial to the collaborating universities without compromising their areas of competition. It is such a large task that it cannot be left to a single institution. Ultimately all can benefit if all participate.

The focus of collaboration could extend to:

- Sharing projects in project based learning,
- Encouraging interaction between student teams in different universities,
- Identifying e materials available on the web that are suitable for the assistance of students as they address particular topics or projects,
- Facilitating local co-operation and interaction with industry,
- Sharing staff development programs related to preparing staff for their role in a transformed education program,
- Sharing laboratory program development,
- Negotiating favourable terms for access to software for engineering problem solution, modelling and simulation,
- Negotiating favourable terms for students to purchase personal computers and e reference books,
- Reducing costs through cooperation.

With a capability driven, project learning based curriculum the first two years could be structurally identical in all universities, while varying in the detail as a result of the variation in projects. Sharing project ideas and the detailed reference materials required to support mathematics, science and engineering principles, can significantly assist both staff and students and avoid duplication of development work. It is envisaged that a student website would be established to assist students and a staff web site would support staff, with web-masters controlling the organisation of, and ongoing contributions to each site. Such cooperation could be local, national or international.

International cooperation, via ICT, if common language permits, could enable:

- Electronic interaction of students in an international project team
- Project teams to work on the same problem cooperatively or competitively
- Projects relevant to developing countries to be studied by students in other countries

- Extension of access to learning materials, curriculum design, staff experience, laboratory activities, educational strategies, etc.
- Some universities to access support that may be required to facilitate the achievement of the international standards/ benchmarks,
- Facilitation of student mobility or exchange,
- Assistance to universities that seek to plan, commence, revise or evaluate engineering education programs,
- Staff interaction, mentoring and exchange.

The vision also embraces the possibility that IT-based teaching and learning practices would be supported by an active community of academic staff and students who create, share, and modify IT-enabled educational materials. This community could advance the goal of effective learning by sharing their experiences and creating improvements. The dissemination of IT-enabled teaching and learning resources would be supported by the novel legal framework (e.g., open licenses and attribution systems) that promotes creation and sharing, while maintaining incentives for authors (including individuals, teams, and institutions) to create and distribute or assemble and improve high-quality learning materials.

Guidelines for Open Educational Resources in Higher Education, which can facilitate such interaction and cooperation have been recently published by the Commonwealth of Learning and UNESCO [97] with the objective of "encouraging decision makers in governments and institutions to invest in the systemic production, adaptation and use of OER and to bring them into the mainstream of higher education in order to improve the quality of curricula and to reduce costs."

6.9 Course Articulation

As noted in Section 6.2, it is suggested that a common first two year program can develop a foundation appropriate for a discipline focussed professional engineering degree program when it is followed by a further two years of education. It is assumed that entering students have completed an appropriate secondary school program with a mathematics and science specialisation. The trend around the world is to have more citizens in the 26-30 age group with post-secondary education qualifications. A common objective is to have 40% with such qualifications by 2020. This also leads to a widespread interest in attracting more students from disadvantaged backgrounds into engineering courses. This trend is likely to increase and there is no reason why such students given opportunities, support and individual motivation should not succeed. Their pathway into an engineering degree program may be non-traditional via a vocational program where the complementary skills developed may be of considerable value. However the initial barriers can be high and ways of lowering these through the provision of appropriate bridging activities is considered essential for their success.

The engineering workforce also requires engineering associates, whose skills are related to the implementation of engineering projects under the direction of professional engineers. Their attributes have been specified in the Sydney Accord [98]. It is suggested that they could also undertake the common first two year program to obtain a broad orientation to the engineering industry. Those who then choose to follow a more hands-on practical career, or those whose abilities are judged as being more suitable for such a career, then undertake a practical skills based third year relevant to a particular engineering field to qualify as an Engineering Associate with the appropriate attributes. This would be quite efficient, while also permitting Engineering Associates to re-enter the third and fourth year engineering programs, if they subsequently wished to do so.

6.10 Program Economics

An important issue for universities is the relative cost of the existing engineering education strategies compared to the proposed model utilising Project Based Learning and student- centred learning strategies. Cost is a critical issue for universities as they all operate under resource constraints. Those dependent upon government funding are more likely to face income reductions than increases, in real terms over future years, even though there has already been a pattern of significant increases in the student/staff ratio over recent past. In the current financial situation, it is likely that public funding will be even more difficult to obtain.

Additionally traditional private campus-based universities may need to reduce the cost of their programs, or students will migrate to the already rapidly growing on-line universities, which provide an attractive alternative for some students. Cost reduction needs to be achieved while providing a high level of personal care and attention to support the development of each student. Also the capability of graduates cannot be compromised. The transformation of engineering education outlined in this report can result in enhanced productivity (lower cost per graduate) and this provides another compelling reason for transformation to be addressed as a matter of urgency.

The critical parameters which determine the economics of any program are average class sizes and the total hours of staff involvement. Major gains are created by the following aspects of the changes proposed:

- A common first two years for all engineering students reduces significantly the number of courses presented and consequently reduces staff preparation time, improves resource utilisation, enhances efficiency, reduces overheads and allows efficient group sizes.
- A program that is student-learning based permits the elimination of lectures and shifts the responsibility for learning to the student. There is a dramatic reduction in formal presentations with a reduction in the amount of formal staff contact time with students. Using a tutorial format with significantly reduced overall contact hours can achieve a significant increase in learning facilitation.
- In the transformed system, learning facilitation is an important component of the interaction available to assist students as they work in their home-room. The home-room numbers can be up to 50, which could be about 10 project teams at any time. Facilitation can be on-call for senior academics, supplemented by regular visits or appointments. More extensive contact can be provided by a mix of junior academics, graduate or research students complemented by engineers from industry, retiree volunteers, alumni or senior students.
- The use of on-line learning resources can eliminate a very large part of the load normally placed on academic staff to prepare “original” lectures.
- The implementation of collaboration between staff and between universities can further reduce costs associated with preparing advice to students about the most appropriate on-line resources for particular topics, can lead to sharing of proven project ideas, can share information for staff ideas and resources, and can lead to cooperation in staff training/development programs and educational enhancements.

Additional costs will be incurred initially to:

- Establish suitable home-room environments, possibly by the conversion of lecture theatres.
- Provide the necessary IT hardware, software and systems.
- Review, and where necessary renew, the laboratory facilities to meet the requirements of the project oriented program, and to introduce experiments to the home-room environment.
- Develop staff understanding of,

commitment to, and preparedness for, the implementation of the new educational strategy.

- Modifying some university policies and practices (e.g. assessment, work experience, e-portfolios) to accommodate the requirements of a transformed educational experience.

These costs should also be offset by improved student retention and success rate, enhancement of graduate achievements, improved relations with employers and the identification of more relevant programs for the engineering research activities of the staff.

6.11 Programs for Developing Countries

It is important to consider the following question: Does the above discussion apply to developing countries? The principles for an excellent engineering program that have been considered and summarised in Section 5.11, are applicable to engineering education in any country. Similarly the program structure, which is very general, can be utilised anywhere. However the details should be tailored to the needs and situation of the particular country. The important constant is that the engineering graduates should be adequately prepared to perform as professional engineers in their country. The development of the students capabilities should be focussed upon their acquisition of the graduate attributes so that they have the capability to implement engineering solutions appropriate to their country's needs. The projects that they undertake should reflect the problems which are relevant to the local situation. The projects will differ, technological solutions will differ, the economics will differ, the materials that are most appropriate may differ, but the engineer's role is to develop the most suitable and socially responsible solution for their community and country. The engineer's skill lies in being able to analyse complex situations, to develop appropriate innovative and cost–effective designs and to implement solutions that can deliver responsible benefits to the community and their employer. The Contributed Panel authored by Professor James Trevelyan emphasises the importance of the social skills and personal capabilities of engineers as they seek to make a difference through the provision of leadership, by the application of engineering knowledge, which is committed to the development of their nation. The World Federation of Engineering Organisations has recently produced a comprehensive report [99] in which the Appendix addresses the Special Policy Needs of Developing Nations. They emphasise:

- The need for multi-disciplinary graduates,
- Strong business acumen,
- A commitment to retaining engineering professionals and encouraging the return of those who have emigrated,
- Specific attention to the possible impact of disaster incidents,
- Application of risk management approaches,
- The need to identify appropriate affordable and sustainable technologies that take cultural and community matters into consideration,
- The importance of the personal graduate attributes being developed in a manner appropriate to the needs of the national circumstances.

As noted previously it is easier to commence an engineering education program that follows the transformation model than it is to change an existing program. Since developing countries are often expanding their university education systems, this provides an opportunity to introduce new programs that are effective and relevant, by following the principles described in this publication, instead of replicating existing programs. As engineering activities are often international, as well as being multi-disciplinary, it may be advantageous for the programs to be undertaken in English which is achieving international language status in engineering practice. This also has the advantages that interaction with other international students is facilitated, and that joint projects can be conducted which are relevant to the developing country [100]. Additionally, Engineers Without Borders may be able to provide assistance with some project coordination.

Contributed Panel No. 14:

From Graduates to Experts? Engineered Roadblocks on the Path to Global Prosperity

Professor James Trevelyan

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We need millions of expert engineers to ensure a safe, sustainable and prosperous future for everyone on this planet. Engineering education capacity is steadily expanding thanks to new capacity, particularly in South Asia and China. Yet, how many of these emerging graduates will ever work as engineers? How many will become real 'expert' engineers? How could we recognize an expert engineer? These are all questions that research on engineering practice is helping to answer. The research, however, has also highlighted some troubling findings. For example, engineering educators are (inadvertently) reinforcing mistaken ideas in the minds of graduates that can block all but a few from becoming experts.[1] The same research could provide insights needed to clear these roadblocks and empower young engineers to help free billions of people from the grinding poverty that is a daily reality for much of the world's population today.

Take Pakistan for example. These boys were walking home from their school past a new mobile phone tower in Ali Pur Farash on the fringe of Rawalpindi in 2007. Today, there are more than enough mobiles for every adult in Pakistan to have one and they cost less than 1 cent per minute for talk time. Yet, at the same time, the water supply for this village was intermittent and unreliable. Some villagers had paid up to $1,200 to install their own well with a hand pump. Before we installed an electric pump at their school, the children had to carry water in buckets for up to an hour a day just to use the toilets. At a similar school in Hyderabad, India, the principal told me that the brown water turned dark green and smelly after it dribbled from the pipes for an hour or so every other day. They did not have a toilet

because there was not enough water, so the children and staff had to leave after a couple of hours.

To understand why these villagers were prepared to pay so much for a hand pump, I turned to development economics. The shadow price cost of unpaid labour could explain this: the only real alternative is for women to carry water from nearby wells. At 10-15 cents per hour, a one hour round trip to carry 15 litres of water amounted to a bulk water cost of $8.50 per tonne, around $15 after boiling to make it potable.[1,2,3,4,5,6] At the same time, water was being delivered to my house in Perth at a marginal cost of 70 cents per tonne. I checked, rechecked and double checked my data. No matter which method, carrying water, bribing government water carriers, installing a hand pump, or buying potable water in 20 litre plastic containers: the cost was at least 20 times what we paid in Perth at the time.

Energy is also many times more expensive. With intermittent supplies, one needs a generator to run electrical equipment reliably. Using electric energy with typical inefficient and poorly maintained machines costs 4-5 times more to achieve results comparable with Australian expectations. Bulk users like steel plants have reported to me that they pay twice the electric energy cost of their competitors in industrialized countries. These high costs for essentials provide a powerful explanation for the poverty that stubbornly remains despite economic and political reforms.

Not all prices are so different. Rice, a tradable commodity, reflects the world market price in both Australia and Pakistan. Neither water nor electricity can be traded on the world market. Therefore, the costs of these engineered utility services must reflect entirely local factors.

Could corruption explain the high costs of electricity and water? It is not hard to find, but reliable sources provided data revealing that the usual cost of dishonest behaviour (and restraining it) increases costs only by about 15-25%. There had to be other factors. My first-hand experience employing Pakistani engineers to develop new demining technologies had required me to recalibrate my Australian expectations of engineers' performance, even though some had degrees from the best UK universities. This experience led me to research the possibility that engineering practice differences could be a major contributing factor.

Surprisingly, I soon ran into an unexpected obstacle. There was almost no reliable systematically collected research data that could provide a detailed understanding of ordinary everyday engineering practice, anywhere. To cover this knowledge gap, my students and I have interviewed and shadowed engineers across the region. We have recorded detailed observations on maintenance, manufacturing, water and sewerage engineers in Australia, Pakistan and India, telecoms engineers in Pakistan, Australia and Brunei, and many others.[7,8,9,10,11,12,13]

Through this research, I realised that engineering practice, what engineers do in their daily work, was largely unknown, even to the engineers themselves. Only a tiny number of earlier research studies had revealed any details, and then only in exotic high-technology engineering that only a tiny number of engineers encounter in their careers.[14]

Engineering has been invisible to nearly all of its participants. Many engineers, on being asked for an interview, would reply "OK, but I hardly do any real engineering."

Why is engineering invisible?

The results of engineering are all around us: e.g. phones, buildings, roads, vehicles, aircraft.

And there lies the trap: these are all objects, some of them vast systems of man-made structures, others almost too small to see.

Why is engineering invisible in these objects?

Engineering is a human performance: it is performed by people. Extraordinary people in many cases but most of them are entirely ordinary people. It is the visible evidence of their performances, the objects and the information left behind, that we associate with engineering.

Engineering artefacts, drawings, objects, documents: each represents for the most part what is to be, or what has been built, i.e. the finished objects. What they do not represent is the human process that led to their creation, and the creation of the objects that they represent.

One of the great mysteries of the ancient world is the techniques used to construct the great pyramids of Egypt. Even with the prolific hieroglyphic writing that litters the remains of the entire ancient Egyptian empire, no one has been able to find any accounts on how the pyramids were built. Engineers today are no different from the Egyptian forebears. The documents and artefacts we create represent the endpoints of our performances. How these artefacts came into being, and the human engineering process, is no more likely to be written down now than it was 4500 years ago. It remains as it always has been, invisible.

To understand engineering we need to learn about the people who do engineering, the engineers that make it happen.

It would be unusual to find an engineering academy that includes detailed studies of engineers, or even people, in the core curriculum.

Engineering academics publish somewhere between

200,000 and 400,000 technical papers every year on engineering scientific advances. Yet only two or three research articles appear each year on what engineers really do in their work, and almost always in journals of little interest to engineering educators.[15,16]

Engineering practice, therefore, is one of the world's best kept secrets. It seems inconceivable that young engineers are taught be people without a clear understanding of what they will do in practice, yet this is the reality today in most engineering schools.

Nevertheless, few would dispute that engineers have, and continue to drive prosperity in the industrialised world. The contrast between the industrialised high income countries and low income countries like Pakistan highlights one of the vital factors missed by engineering educators: the value created by effective engineering.

Our recent research has revealed that engineering education is silent on the economic value of engineering, both for a society and for individual enterprises. This helps to explain research findings that young engineers cannot explain the value of their work for clients or their firms. (The recent UNESCO report preceding this one is equally silent.)

At a macro level, good engineering results in higher quality products and services delivered for a fraction of the cost, as demonstrated by the relative prices of non-tradeable electricity and water services mentioned above. In industrialised countries, engineering ingenuity to reduce costs has been a response to economic incentives.

Many people see engineering as applied science, and scientific principles apply equally in Peshawar and Perth. This notion suggests that engineers should produce similar results anywhere. Research not only demonstrates that this notion is false but also explains why.

A large part of the answer lies in understanding engineering as a human performance, like an orchestra. Just as players can create a fantastic symphony from coordinated diverse instrumental sounds, engineering relies on expertise distributed in the minds of diverse participants. From artisans to accountants, predictable results in good engineering come from countless individual and, to a degree, unpredictable daily human performances. The end results are as dependent on the quality of social interactions among the participants as the strength of steel. Survey data reveal engineers average 60% of their time on direct communication, regardless of experience level, discipline, setting or country. Some may call this teamwork, but it is quite different. Many of the participants follow an unwritten score, and most are only dimly aware of the rest of the orchestra. Informal technical coordination by engineers lies at the core.[11]

In South Asia, hierarchical organizations and deep social chasms disrupt this coordinated performance.[1] For instance, artisans will only speak when asked, and will keep silent if speaking means loss of face for superiors. A tiny number of 'expert' engineers can bridge these barriers, and they earn salaries higher than their counterparts in Australia. This is no surprise, because they make their enterprises work, and in doing so generate more than enough value to offset their extremely high salaries (compared to local norms).

In such settings, systematic research can help us recognise an expert engineer. They stand out partly for their ability to converse with clients and devise ingenious combinations of artefacts and information to satisfy their needs economically. Mostly they stand out for their ability to coordinate predictable on-time delivery with promised performance, capital and operating costs, safety, reliability in service, and environmental impact.

Yet these experts are so few in number that most young South Asian engineers never get opportunities to witness their mostly unwritten skills and dedication. Even though students in Australian engineering schools learn few practice skills, there are usually enough experienced engineers in most firms for young engineers to learn from. It still takes them three to five years and many never learn, leaving the profession in frustration.

Can this idea explain why telecoms engineering been such a runaway commercial success story in South Asia, in contrast to the creeping disaster represented by partly dysfunctional water and electricity utilities? There are technical factors, of course. However, the engineering coordination seems to have worked well, possibly because nearly all of the participants can communicate in English and the few remaining social divides have been bridged by smarter work practices.

Through research, we can understand why this success story can lead to solutions for endemic and persistent poverty in low income countries, the dream of many engineers. When daily essentials like water are so much more expensive than in Australia, it is no surprise that most people in Pakistan and India are poor. Fixing engineering practice, especially in water and energy distribution, could change all that, for ever.

It could take decades for education institutions to catch up with these ideas because traditional notions of engineering as an exclusively technical discipline are so deeply entrenched. However, the disorienting experience encountered by young graduates in their first jobs may provide a fertile opportunity for intervention.[12,16,17,18] A few key ideas have the potential to open their eyes to the great opportunities that await them.

First, they need to know about the tiny number of really successful expert engineers that can be found in any country. Especially in a low income country, young engineers need to understand that they can earn as much or more at home as they could in any industrialised country, provided they can learn to become expert engineers and that an engineering degree is just the start of that journey.

Second, they need to understand the importance of learning about social interactions, and why social interactions are so critical for expert engineers.

Third, they need to understand how expert engineers create useful economic and social value, particularly by reducing uncertainties contributed, in the main, through unpredictable individual human performances.

Policymakers can help. They can help locate expert engineers and make their stories accessible for novices. They can create opportunities for foreign engineering firms to employ and train local novices, and to provide novices with opportunities to experience engineering practice in an industrialised setting.

Finally, educators can help as well by understanding the many misconceptions introduced through conventional engineering education. Understanding could help remove many of these roadblocks.

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6.12 Post-course Professional Development

It was noted in Section 3.1 that the major international agreement in relation to the registration of engineers specifies a two stage process where universities provide an educational experience to develop knowledge and the essential specified graduate attributes which permits entry to the profession, and then there is a period of formative development, which could be the joint responsibility of the employer and the university, to enable the standard required for registration as a professional engineer to be realised. In practice the formative stage may be undertaken primarily through a post-graduate coursework or research Masters degree program within a university, or it may be primarily undertaken through a well-planned set of development projects within the employers portfolio of projects. While this phase of the development of engineers is not the primary focus of this publication, it is appropriate to record some relevant observations in relation to the continuing development of an engineering graduate, from within a nurturing and supportive environment where they have been encouraged to think laterally and creatively across a range of topics and issues, to become a professional engineer who has proven that they have the capability to act independently, responsibly and effectively at the forefront of a specified field of engineering practice. The capability for independent life-long learning must have been demonstrated. The employer should consistently expect the graduates of transformed engineering programs to maintain and apply this capability.

In undertaking this next development phase of a graduate engineer, the opportunity for a closer partnership between universities and employing organisations appears to hold benefits for both. They have complementary strengths and if they worked together on this area of activity where the basis for cooperation is fairly obvious, it could be an effective stepping stone for even more beneficial mutual cooperation in projects, development, innovation and research. The result could be enhanced workforce capability within the commercial engineering organisation, and a greater relevance to the engineering profession within the university, to the benefit of employers.

The vision of shared participation and cooperation between industry and academia is full of possibilities! A structure for regular meaningful interaction, between the engineering managers of both parties that are committed to cooperation, should establish defined outcomes and mutual benefits, as the first step towards the realisation of these mutual benefits. It is not common for these partnerships to become sufficiently close for these potential benefits to be realised. The understanding of the constraints that each party operates within are seldom made sufficiently clear to each other so that they can create, and operate, as a single team sharing expertise, objectives, facilities, risk, rewards, plans and constraints.

7. The Challenges of Curriculum Transformation

As has already been noted, achieving change in universities is difficult: implementing transformation is even more difficult. Universities are more comfortable with the continuation of practices that have been used for many years. While, encouragingly, there are some examples of successful implementation of program transformation, as has been noted, they are few. The factors that need to be addressed before change can be confidently established are numerous and complex. It requires thorough planning. Consequently it is advocated that some trials be initiated, after thorough development work, and *rigorously* evaluated. It would be beneficial if they could involve the co-operation and collaboration of a number of universities, who would then be able to share the benefits of the experience. Trials of change seem to be the best way to work through the many issues that need to be addressed. The trials should be undertaken with the objective of developing materials and experiences that can be shared with other universities. A small trial is scheduled to commence in a new degree program in Sustainable Systems Engineering at RMIT University, Melbourne in 2012.

The transformed engineering education system should deliberately aim to be collaborative. The existing competitive environment is inefficient and unhelpful in producing the best possible outcome for students, employers and countries, particularly when the financial constraints faced by universities are currently significant and they are likely to deteriorate further in the foreseeable future. There is no significant disadvantage in cooperation which sees a sharing of program design, project ideas, and the available web-based course material. The benefits would include better student outcomes, reduced load on staff, quicker transformation and lower costs.

7.1 What is Involved in Transformation?

Summarising the points developed previously, it is suggested that transformation of engineering education requires changes to the engineering curriculum and changes to the teaching and learning processes. It also requires:

1. Professional Engineering Institutions responsible for program accreditation to ensure that each university can demonstrate that ***each*** of the graduate attributes specified in the Washington Accord are achieved by ***all*** the engineering graduates of their university.

2. Universities to be committed to the achievement of these attributes by all graduating students, by adopting them as the program objectives and being able to demonstrate the achievement of each attribute by appropriate assessment practices. This may necessitate changes being made to university policies in relation to course structures and assessment policies.

3. The engineering faculty to revise the engineering education program and curricula to enable the focus to be directed to the student’s development of the broad capabilities required of engineers, in contrast to the current emphasis on technical knowledge. The achievement of these desired engineering attributes and capabilities to be facilitated through the utilisation of project based learning as the core of the engineering education program, commencing in year one where it will assist to motivate students.

4. Engineering academics to foster student-centred learning using web-based materials and other learning resources assisted by tutorials, and to facilitate the creation and operation of learning communities as a more efficient strategy to achieve student development than lecture-based teaching.

5. Students and academic staff to work together to regularly monitor and record the progress toward achieving the specified learning outcomes to optimise

the effectiveness of student learning as part of the quality management processes.

6. Universities to provide suitable "home room" work spaces and facilities for engineering students to undertake their projects and active learning, with the support of experienced facilitators, and access to laboratories for technology exploration and workshop facilities for design and build exercises.

7. Universities to ensure that students are exposed to current engineering practice and projects through work related experience and/or interaction with experienced engineering personnel, with the cooperation of industry as necessary. This may require some modifications to the structure of the academic program.

8. Universities to ensure that students have access to staff with professional engineering experience.

9. Lectures to be relegated to special occasion activities.

10. Laboratory programs to be designed to provide learning experiences consistent with the program objectives and with relevance to the student's projects.

11. Academic staff to ensure that the assessment of students is designed to establish their level of achievement of the desired graduate attributes.

12. Employers that are committed to the future of the engineering profession, develop meaningful ongoing relations which provide effective assistance to the universities that are committed to introducing the required transformation in engineering education.

13. Appropriate IT systems and software packages are available to support the student projects and student learning.

7.2 Barriers to Transformation

While the above changes are easily summarised, they are difficult to implement because of the complexity of university organisations, procedures and attitudes. A major difficulty is the culture that typically exists within universities. Change requires staff support and participation, but academic staff may be resistant to change for a number of reasons. They have a dominant relationship with students and are not comfortable if that is challenged, or that they are placed in a position where they are required to operate beyond their expertise range. They are also reluctant to change from an approach that they are comfortable using, and may have used for many years, and the status that it automatically accords. Some academic staff may also be challenged by the greater IT literacy of the students.

Academic staff members are commonly employed on the basis of their research activities and they operate with considerable independence that is derived from their professional capabilities. They are protective of their current teaching activities as a matter of priority, however, rather than focusing on what may be best for students, when improvements that change the educational structure or strategy are proposed.

In university culture, research has a far higher status than teaching and it is also the major factor in appointment, promotion and teaching load reductions. The recent trend to appoint some "teaching only" staff only exaggerates this status demarcation. Academics are selected on the basis of their specialist skills and they are devoted to activities that use and develop this capability further and create a special relationship with students who show a special interest in their area of their expertise. They seldom have knowledge of education as a discipline beyond that gained through their own experiences. These issues can act against a major change of educational philosophy and practice, particularly as it is proposed to reduce the technical specialisation component in the professional degree program. (Some of these specialised topics could be deferred to the program for professional development discussed in Section 6.12).

An enhanced emphasis upon the practice of engineering may expose a major gap in the experience of many academics. Also, the status of their discipline group is more likely to be determined by its research standing than by effective teaching. Changing the approach to teaching would be seen as very risky if other institutions were not also changing. What has been done for years must be satisfactory by definition! Changes of direction, responsibilities, role, activities, policies, procedures, or priorities are likely to be opposed by the majority of academics, unless an understanding of the need for change is created and there are some major offsetting benefits.

Leadership for change must come from within the universities, but it can be greatly assisted by the encouragement of stake-holders, in particular: engineering employers, past graduates, professional engineering organisations and government. It is likely to require some incentives.

7.3 Taking Steps Toward Transformation

The following are some possible steps that may be taken towards achieving transformation:

- Professional engineering accreditation authorities accept their responsibility to ensure that the graduate attributes specified in the Washington Accord are demonstrated by all engineering graduates.
- That they communicate how they will undertake this assessment of graduate capabilities to universities.
- That the professional engineering bodies assist potential students to better understand the interesting roles and challenging activities of professional engineers and play a major role in assisting to attract more students to commence engineering studies by promoting the changed approach to engineering education which is being implemented.
- That they also endorse the need for universities to transform engineering education in a manner consistent with this publication and require transformation to be completed within a period of 10 years for accreditation to be retained.
- That the engineering faculty of the university hold workshops involving professional bodies, employers and senior academic staff to discuss how this change can be realised most effectively with a cooperative partnership. It is likely to involve program, curriculum and pedagogy change, work experience opportunities for students and the employment of staff with engineering experience.
- That forums be conducted with interested academics, employers, graduates and students for the purpose of exploring the issues associated with the possible implementation of the recommendations of this publication.
- Opportunities for post-graduate learning programs, that are supported by industry, or delivered co-operatively, to be provided by the university, may also be discussed as a means of achieving the transition of graduates to full professional registration.
- That industry be requested to suggest engineering project ideas suitable for undergraduate student projects at all levels and to consider making available some engineering staff to participate as casual student learning facilitators or tutors.
- That the university provides a “home room” with an engineering office environment for all engineering students.
- That the university consider how to make learning more student-centred. That

"learning without lectures" is trialled with students actively represented in planning, implementation and evaluation.

- That the learning resources available on the web be investigated for use in some specified topics for trial learning experiences and shared with all local universities.
- Industry may be requested to advise of suggested simulation/modelling/design software packages that the university should acquire and to assist with the development of operational expertise.
- That the students are involved in discussion of any possible changes and that their evaluation/feedback is sought following all trials of changes.
- That the universities recruit more academic staff with experience of professional engineering practice.
- That consideration is given to sharing experiences with other universities in a co-operative manner to reduce costs and to gain experience and ideas.
- That the governments provide incentive funding to public universities (in the public interest) to facilitate an increase in the number of engineering graduates. These funds should be dependent upon the commitment of the university to the transformation of engineering education. The funds would be available to change university facilities, to acquire new software and laboratory resources, to develop and trial new programs and to increase student numbers.
- That a review of laboratories to enable more effective support of project based learning be conducted.
- That the trials of transformed engineering education programs be rigorously evaluated.

7.4 Establishing New Engineering Education Programs

Countries or universities that are considering the establishment of new engineering programs are strongly recommended to introduce programs that are consistent with the principles enunciated in this publication and not to model their programs on those of existing universities unless they are also undertaking a transformational strategy. The reasons for this are:

- It is easier to follow these principles when there is no existing program, than to convert an existing program; however, sometimes small changes in existing programs can have a large effect.
- The benefits of the transformational model are considerable in producing engineers with the required capabilities.
- It is beneficial to commence in the direction that predicts change rather than to follow.
- The cost/benefit ratio favours this strategy.
- The program can be readily tailored to be relevant to national requirements.
- It can readily grow from small start-up numbers if necessary.
- It will reflect the technologies of future importance to the country or location.
- It can provide a breadth of engineering capability that may be readily complemented by adding specialisations in the areas of engineering capability that are required as national development proceeds.

8. Towards Transformation

8.1 A New Model of Engineering Education

A new model of engineering education is needed as described above. The lecture plus tutorial model has been pushed about as far as it will go. Students are turning away from lectures, which they find too boring. This is the always online, iPad, Facebook, iGoogle generation, at ease with instant access to information [101]. Students need more flexible ways of learning engineering and demonstrating engineering expertise.

In this new way of engaging students we need to find the means to implement a radically different socio-technical approach. The following key ingredients have been proposed, all of which have been field tested, but are not yet available at any one institution:

- A project-centred curriculum, as outlined in Section 6.2, (either a spine of project-based subjects supported by learning modules, or through learning modules that have a combination of theory and project in each module).
- Learning modules on-line that provide the engineering fundamentals to support the projects.
- Assessment of the professional skills through the projects, undertaken by interview and other interactive methods, plus
- Assessment of the technical skills through the learning modules. This will be easily done through online assessment supported by pen and paper tests as required.

8.2 Projects Promoting Enabling Skills

Engaging students in the engineering design process (through projects or problem solving in general) requires more project work than is currently used to deliver engineering programs. Within these projects, **students will be expected to acquire new skills.** This moves project-based learning closer to the original intent of *problem-based learning*, where the problem drives the learning of new knowledge and skills [102].

There is a need to move from a focus on knowledge creation, supported by some skill building, to a focus on complex problem solving. Students need to be able to observe, to be involved in, and become capable to, apply engineering techniques in complex, real world situations. They need a lot of practice at this, because each project has different issues and presents different challenges. The objective is to provide students with a number of experiences until their ability to undertake such projects successfully and responsibly can be assured.

Examples include: water supply for cities impacted by reduced reservoir inflows caused by climate changes, water supply and sanitation in developing nations, transport in megacities, global trade imbalances, sustainable energy, recycling, etc. These are the problems that the next generation of engineers will face. They need to be equipped with the capabilities required for their resolution. The NAE's Global Engineering Challenge has already been discussed.

Students will also tackle these problems within a global workforce, where they work on engineering teams spread across the globe [103]. They need to develop cross-cultural awareness and skills for cross-cultural communication and decision making [104].

Of course, students also need to be able to easily learn new technical skills, because otherwise they try to keep applying existing, inappropriate skills when a new skill or insight is needed. "Every task looks like a nail if the only tool you have is a hammer". This is the essence of lifelong learning.

So, students need to be able to move from the project task to skill development and back again.

This matches the situation they will be confronted by in industry, where new skills are required for new projects. These new skills might be acquired from Internet resources or from colleagues near-by or far away in global engineering companies.

A simple model divides the curriculum between project work and skill acquisition:

Projects represent engineering practice.	**Skill acquisition**
Students must have passed the relevant modules to be admitted to the project (or the modules need to be completed during the project). Some of these will be design tasks, eg the SAE Formula racing team [105]; others may be research. Some will be community service such as Engineers Without Borders or industry projects. The whole engineering lifecycle should be represented.	– can increasingly utilise computer-based skill development combined with **computer-based assessment.** Students may progress at their own pace and are likely to progress faster than they do at present [106]. These online activities could be supported by workshops, laboratories, student discussions and facilitated tutorials.

Skill development can be refocussed away from the lecture-tutorial approach toward individual student utilisation of the good online resources now available (see below). This approach needs to be more widely advertised and adopted. They can be supported by *online assessment* so that students can develop skills at their own pace and test themselves to make sure that they have got it right. This approach is still underutilised as a consequence of the current emphasis on delivery of content rather than the outcome which is effective learning and its assurance through assessment. However, major publishers such as Pearson and Wiley already have online assessment available for many of their engineering publications.

Verification of computer-based assessment may be done under exam conditions, but not necessarily in the traditional exam period. Students will have a record of their competence in their e-portfolio as discussed in Section 5.6 [107]. It may be that the technical subjects, learnt with these methods, should be assessed more rigorously using a *mastery learning* approach, with a pass mark set at 75% instead of the usual 50%. Students can keep trying until they reach the required level of competence [108-110].

Many students will complete more than the minimum set of modules because they will complete the work more quickly [111-112]. This will free up time for staff to create and conduct more complex learning situations for students – the project-based component of the curriculum as undertaken in the Khan Academy. (http://www.khanacademy.org).

So, the basic curriculum elements should look like this:

Project ≈ engineering practice	**Skill acquisition** through online module 1
The project focuses on a real problem. This problem motivates students to integrate what they already know and also to acquire new skills via learning modules 1-5.	Module 2
	Module 3
	Module 4
	Module 5

8.3 Project Example from Civil Engineering

Consider a traditional unit in the design of a high-rise building, made up of these learning objectives [113]:

- Describe the multi-disciplinary nature of designing a tall building and the role of a structural engineer in the design of tall buildings.
- Describe the design criteria and loading conditions for buildings.
- Calculate dynamic wind loads on tall buildings using the dynamic response factor approach.
- Interpret wind tunnel test results to obtain equivalent wind loads.
- Develop approximate models for analysing structural systems in buildings.
- Develop computer models for analysing structural systems in buildings.
- Identify and analyse different structural systems using case study buildings.
- Develop conceptual designs of floors using different floor systems.
- Develop conceptual designs of lateral load resisting systems for buildings.
- Develop conceptual designs of foundation systems for different buildings and soil types.

In contrast, a project-driven curriculum may not cover as much technical background, but would include some additional topics:

- Wind loads, earthquake loads and possibly terrorist loads.
- Structural frame conventions (central lift core versus alternatives).
- Design for fire and emergency exits under extreme conditions.
- Sustainability (green star rating) – lifecycle costing.
- Multidisciplinarity – multiple engineering disciplines, system considerations, interface with architects and/or other professionals, building service engineers, cost estimators, project managers, social responsibility.

Implementing the project-based approach to the design of a high-rise building could involve the following learning modules:

- Loads on buildings: dead and live loads, wind loads, earthquake loads, explosive loads.
- Wind loads: estimating wind loads for high-rise buildings.
- Common structural systems for buildings.
- Software for structural analysis: implementing common analysis methods.
- Lateral loads on buildings: design considerations.
- Design of piled foundations.
- Design for fire and explosion.
- Emergency exit design.
- Life cycle assessment.

The following table shows some additional examples from civil engineering:

Table 1: Project examples from civil engineering.

Subject	Project Scope	Learning Modules
Water		
Floods	Flood plain assessment	• Impact of climate change (more extreme weather events) • Assess impact on a coastal or regional community • What needs to be done to reduce potential impact in next 20 years? (planning/rezoning, levies, insurance)
Geomechanics		
Cuttings & Excavations	Design of rock fall barrier	• Developing a geotechnical rock model from field data • Consider various design options • Develop a rock fall model • Develop a risk estimation model to evaluation cost/ benefit • Design of impact protection barrier
Sustainability		
Civil & Health	Develop a new suburb to encourage healthier lifestyles	• Research beneficial health effects of different lifestyles • Develop a simple economic model for scenario evaluation • Using cellular automata, develop a model of the suburb • Use the model to design a suburb optimized to maximize various objective functions • Could include all basic civil works: roads, drainage, sewers, wastewater treatment plant, electricity and communications
Transport		
Road design	Subdivision	• Road alignments and safety issues • Appropriate software
Construction		
Various	Any of the projects above	• Plan project activities and sequencing • Plan equipment allocation • Onsite safety and health • Environmental protection

8.4 Available Online Resources

What online modules exist to help in this process? There is a series of navigator or directory sites (Table 2) where many resources for all branches of engineering can be found. These include online tutorials (modules), e-books, research papers and some online assessment, as well as links to companies, data and various other documents.

Exploring these sites has revealed a range of resources for learning basic mechanics, as one example (Table 3). There is surprisingly little in terms of assessment of the skills, although there is some self-assessment material. Most sites are focussed on providing tutorial materials.

Table 2: Key directories for engineering education resources.

Directories	URL	Comments
National Science Digital Library	http://www.nsdl.org	85,719 results for “engineering”.
Engineering Pathway	http://www.engineeringpathway.com	15,193 results for “engineering”.
UK Engineering Subject Centre	http://www.engineeringpathway.com/ep/community/eng.jhtml	55 results for “civil engineering”
MERLOT	http://www.merlot.org/merlot/materials.htm?category=2661 (Engineering)	517 results for “engineering”.
Foundation Coalition	http://www.foundationcoalition.org/	Focus on first and second years and curriculum integration
Gateway Coalition	http://www.gatewaycoalition.org	A range of modules and virtual labs
NEEDS	http://www.needs.org	Registration required. Search the library.
SUCCEED	http://succeednow.org	
World Lecture Hall	http://web.austin.utexas.edu/wlh/	Some online subjects.
More specialised directories …		
CDIO	http://www.cdio.org	A particular approach to teaching en-gineering design practice
Geotechnical, Rock and Water Resources Library	http://www.grow.arizona.edu/	865 resources on 16 Jan 2008
HAMLET, Univ. of Maryland	http://www.eng.umd.edu/HAMLET/resources.htm	Great place to start for online resources for basic mechanics.
Carnegie-Mellon Open Learning Initiative	http://www.cmu.edu/oli/index.html	Statics, Statistics, Economics, Physics, Causal Reasoning, Biology, Chemistry, French, Login & Reasoning, Empirical Research Methods
MIT Open Courseware	http://ocw.mit.edu	Click on “Engineering”
More general-purpose directories …		
Virtual Library	http://vlib.org/Engineering	
Intute: science, engineering & technology	http://www.intute.ac.uk/sciences/engineering/	Good overview and tour of web re-sources for engineering

Table 3: Individual sites for learning structural engineering.

Directories	URL	Comments
Buffalo	Interactive Structures http://www.aia.org/SiteObjects/files/Vassigh_color.pdf	Structures for architects and designers
Carnegie-Mellon	Statics http://www.cmu.edu/oli/courses/enter_statics.html	Part of CMU's Open Learning Initiative.
Educative Technologies	Structural mechanics – eWorkbooks and self-assessment http://www.educativetechnologies.net/	Self assessment in beams, frames, trusses, machines
eFunda	http://www.efunda.com/formulae/formula_index.cfm	Basic mechanics
John Hopkins	Truss designer http://www.jhu.edu/~virtlab/bridge/truss.htm	Web-based software
Missouri-Rolla	Engineering Mechanics http://web.umr.edu/~oci/index.html	Statics & dynamics
	MecMovies – Mechanics of Materials http://web.umr.edu/~mecmovie/index.html	Basics to combined stress states
Missouri State	Virtual Laboratory for Structural Mechanics http://www.ae.msstate.edu/vlsm/	
MIT	Engineering Mechanics of Solids http://ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-050Fall-2004/CourseHome/index.htm	Includes TrussWorks and FrameWorks software.
Nebraska, Lincoln	Mechanics Source page http://em-ntserver.unl.edu/	Statics, dynamics, mechanics of materials; supporting maths
Ohio	Statics http://www.ent.ohiou.edu/~statics/	
Oklahoma	Fundamentals of Engineering Review http://www.feexam.ou.edu/	Statics, dynamics, mechanics, materials, thermo, fluids, maths, economics, ethics, electrical, computers, chemistry
	OU Engineering Media Lab http://www.ecourses.ou.edu/	Statics; Dynamics; Fluids; Thermodynamics; Math – Calculus; Mechanics ; MEMS; Multimedia

8.5 Planning the Curriculum

In planning a new curriculum in any engineering discipline, it is useful to consider some fundamental questions [114]:

- What are the professional needs in the discipline?
- What **expertise** is required on graduation? (What should graduates be able to do?)
- What are the required learning **outcomes** to enable this expertise?
- What should students be able to **do** at the end of each **module**?
- What learning **activities** are appropriate to help students develop the expertise?
- What **resources** are required to support students as they complete these activities?
- What resources already **exist,** with a focus on online delivery and assessment?
- What **collaborators** can we engage in the further development of these resources?
- How will we **evaluate** our success and make improvements?

This planning will be an important stage in the building of an online resource for the learning of engineering that will have two major components:

A database of suitable **project** case studies, ready to run.	A set of online **learning modules** for skill development to support the projects, with robust assessment processes.

Such a site would be a very different repository from those in Table 2. Rather than a library-like catalogue of many contributions, it will be organised around the capabilities required within each discipline of engineering. This permits the matching of accreditation requirements (eg the International Engineering Alliance) where capabilities must be mapped against learning modules (subjects or courses). Why should this be undertaken by each university department when collaboration would lead to a more effective and more efficient outcome? Within a collaborative solution there would remain adequate scope for local adaptation and creativity.

8.6 Getting Started with the Fundamentals

One of the most challenging aspects of curriculum design is the first two years. Students come into the university from many different schools and backgrounds, in various degrees of preparation. They need varying amounts of additional preparation to ensure that they can be successful in their chosen program.

In most engineering programs, students enter a predominantly common first year, which takes little account of their differing levels of preparation. This is another reason for a comprehensive suite of online modules. Students should be able to improve their knowledge and understanding of the basics, particularly mathematics, when they enter the university. An online assessment tool can provide feedback to ensure that they have mastered what they need to have mastered.

After first year, students quickly fragment into many different second year streams as individual disciplines pull their students away to learn their specialised materials. This seemed like a good idea in the 20th century when we saw engineers becoming increasingly specialised. However, engineering practice is increasingly multidisciplinary. It is a great advantage for all engineering students to have a broad understanding of all engineering disciplines so that they can work effectively with these other disciplines in project teams.

This concept of a common first two years for all Engineering Degree courses flows from the program structure discussed in Section 6.2. The first two years should focus on motivation and the development of all the engineering attributes: an understanding of scientific principles, familiarity with mathematical concepts and tools, and engineering fundamentals to support multidisciplinary engineering. Using a combination of project based learning courses and online learning modules, as suggested in Section 8.6, what set of subjects would adequately introduce the fundamentals?

The first step is to consider the fundamentals of engineering, which include:

1. Materials from which things are made, including an understanding of small to large structures such as large buildings and machines. Newton's laws, force and moment equilibrium and concepts of stress and strain and compatibility are key topics.

2. For objects that move, such as machines, then an understanding of conservation of energy and momentum, friction and vibration are important, in addition to what is already known about static structures.

3. Water and fluids are the next category of knowledge, also requiring conservation of mass and energy as well as turbulence and friction.

These three items underpin civil and mechanical engineering and a fair amount of chemical engineering. However, in the 21st century, students also need an understanding of the basics of:

4. Electrical equipment, such as motors and transformers, electrical circuits, distribution methods and energy losses. Renewable energy might also be considered.

5. Digital devices such as computers, digital signals, sensors, programming, feedback, and stability.

6. System engineering, which provides a framework to understand the interrelationships and interactions in the world, including with human and natural systems.

Project topics should be chosen to be relevant, interesting, motivating and challenging, address the learning objectives of the program, have relevant resources are available. The following project suggestions are illustrative and have been presented as an idea starter. They need to be given local relevance and variation to ensure uniqueness. Students should also be encouraged to bring their own ideas of what they would like to complete for their investigation.

The concept of using an overall theme for each project simplifies the timing issues with the learning modules, and ensures that there will be mutual interest when they are presented by the project team to their colleagues. However, with a student-centred learning approach to the learning modules, the students in a cohort do not need to be undertaking their learning modules simultaneously. Likewise, there is no clear dependence between the projects so that students can tackle them in any order.

You may be able to think of other project topics. One good source of inspiration is the list of the Grand Engineering Challenges [115].

From these projects, students learn the engineering fundamentals:

- Electrical equipment in engineering, such as motors and transformers; electrical circuits; distribution methods and energy losses.
- Structures: trusses and beams; stress and strain; equilibrium of forces and moments.
- Dynamics of machines; conservation of energy and momentum, Newton's laws of motion; friction; vibration.
- Water and fluids; conservation of mass and energy; pipe flow; sensors and measurement; water chemistry.
- Robotics: digital signals; sensors; programming; feedback; stability.
- Systems Engineering.

So, by the end of second year, the students have seen a range of engineering applications, many of which they interact with on a daily basis, so that their learning is grounded in reality. They will also have seen the basic principles of systems analysis, Newton's Laws of motion, conservation of energy and momentum and they will have developed some modelling skills to predict the behaviour of these engineering systems. One university that has implemented this approach is the University of Western Australia [116].

Project Examples	Learning Module Topics
Electrical Power Generation 1. Identify, evaluate and present the features of the environmentally friendly means of generating electrical energy. 2. Provide details of the operation of solar tower electrical generation systems and evaluate their potential. 3. Examine the methods proposed for the reduction of CO_2 emissions from hydrocarbon fuel power generation plants and comment on their likely effectiveness.	Power and energy Electrical circuits DC & AC R L&C circuits Power distribution systems Generators & Motors Transformers Energy losses
Water Resources 1. Describe all the elements of the system that supplies water to your house/city. What are the performance limitations to that system? 2. How is water contamination prevented in your water supply? Explain the processes used to achieve and control water quality. 3. How are the waste water systems managed? Is there the opportunity for water recycling to be introduced? How could that be achieved? 4. How do desalination plants operate? Explain the technology and the advantages of the various strategies. 5. What are the effects of our water supply and disposal systems on the natural systems with which they are integrated?	Introduction to hydraulics. Flow and flow control Networks (Electrical analogy) Dams as structures Pumps Sensors and measurement Water chemistry
Structures 1. Describe the details of the design approach for a typical industrial building. Now determine what needs to be learned to design such a building. 2. Design an economical, but attractive bridge for a specified span and load. (This could be a competition for the best lightweight structure.) 3. Complete the conceptual design of a high rise building that is to be environmentally responsible. What systems are potentially involved? Can you find examples of civil/structural, electrical, mechanical, telecommunications, chemical, and ro-botic systems ?	Forces and Loads; Moments Equilibrium Trusses and Frames Axial loads – Tension and Compres-sion Buckling of compression members Beams: Bending moments and shear force Stress and strain; Materials Young's Modulus Fracture and failure Design of trusses and beams
Robotics Implement a robotic system to perform a specified task. (This would be an experimental project, using laboratory kits.)	Sensors Digital signals Logic Memory Information technology Computer programming Feedback Stability

Project Examples	**Learning Module Topics**
Transport 1. Provide an overview and analysis of the public transport system serving your community. Highlight its deficiencies and propose efficient improvements. 2. Identify the factors that are delaying the introduction of electric vehicles. Evaluate their likely im-pact on the environment and examine the technology advances required for their widespread uti-lisation. 3. Examine the issues associated with the use of hydrogen as the fuel for private transport. 4. Research Electronic Stability Control. How does it work? What are the main components? You will need to consider the physics/dynamics of cars skidding out of control.	Newton's laws of Motion Conservation of momentum and energy Friction Mechanisms Thermodynamics Engines

8.7 Tracking Student Progress

In an experiential learning system such as this, students need to track their learning achievements in both the online learning modules and also in the projects. The International Engineering Alliance has provided a set of outcomes for a professional engineering degree (discussed earlier). This is an extensive summary of the non-technical skills that young engineers should be able to demonstrate.

A similar list should also be developed for the technical skills, which will be matched against the online modules (and assessment) discussed above. One example of the technical definition of an engineering discipline, for Environmental Engineering, is being developed as part of the Define Your Discipline project [117].

In the online modules, the system would automatically track each student's progress, allowing them to progress to the next module when the current one has been mastered. The Khan Academy is one example of such a system [118].

As well as the online record keeping, both students and staff will keep reflective logbooks to track their own performance and the performance of the educational system. That is, they will take a research approach to teaching and learning: Action Research as discussed by [119]. The basic question is: What can we be doing better? Since this is now a resource-based approach rather than a person-based approach, it is a system easier to improve by buying or developing better resources, most of which will be online as well as by developing better processes to use to support interaction by the participants.

The projects themselves are assessed through a range of measures – reports of various kinds, oral presentations, interviews, tests, and so on.

8.8 Knowledge Management

Large engineering organisations face similar challenges to universities to ensure competence in their people who are spread across the world working on highly complex tasks, requiring them to be active learners on the job. What works for the engineering organisations is to share their knowledge across countries and across time zones, which they do using knowledge management systems (KMS), which comprise:

- Document repositories, past designs and reports, corporate plans, company standards, contracts, emails, current projects, project plans, project timetable, staff members and their responsibilities, consultants, project teams, meeting records, budgets and financial reports, clients, relevant software packages, information relevant to the organisations business.

- Special interest groups (of people) on particular topics, accessible through specialised forums and via email for more private communication.

Employees work by accessing company knowledge first through their own personal networks but also through the formalised networks supported by the KMS. They can ask questions of an expert on the other side of the world and expect to get an answer in a reasonable amount of time. Likewise, they can search the document collection for other projects of a similar kind to the one they're working on.

Likewise, in their project work experiences, engineering students need access to a wide range of knowledge. Some of it will come from friends and acquaintances. Other information will come via the learning management system (LMS). Over time, these learning management systems are becoming much more interactive, with students contributing to the knowledge base through discussion boards, wikis, blogs, and so on. The LMS is looking more and more like a KMS.

Research in higher education has shown that successful students are those who work collaboratively with others. This is also true in the workplace. Therefore, the engineering curriculum must make collaboration fundamental to student learning. This is another reason why project work is the key ingredient in the curriculum. Not only does it help the students to see the connections between theory and practice. It also supports the fundamental nature of human learning: we learn best in interaction with others and assists in the development of this vital attribute.

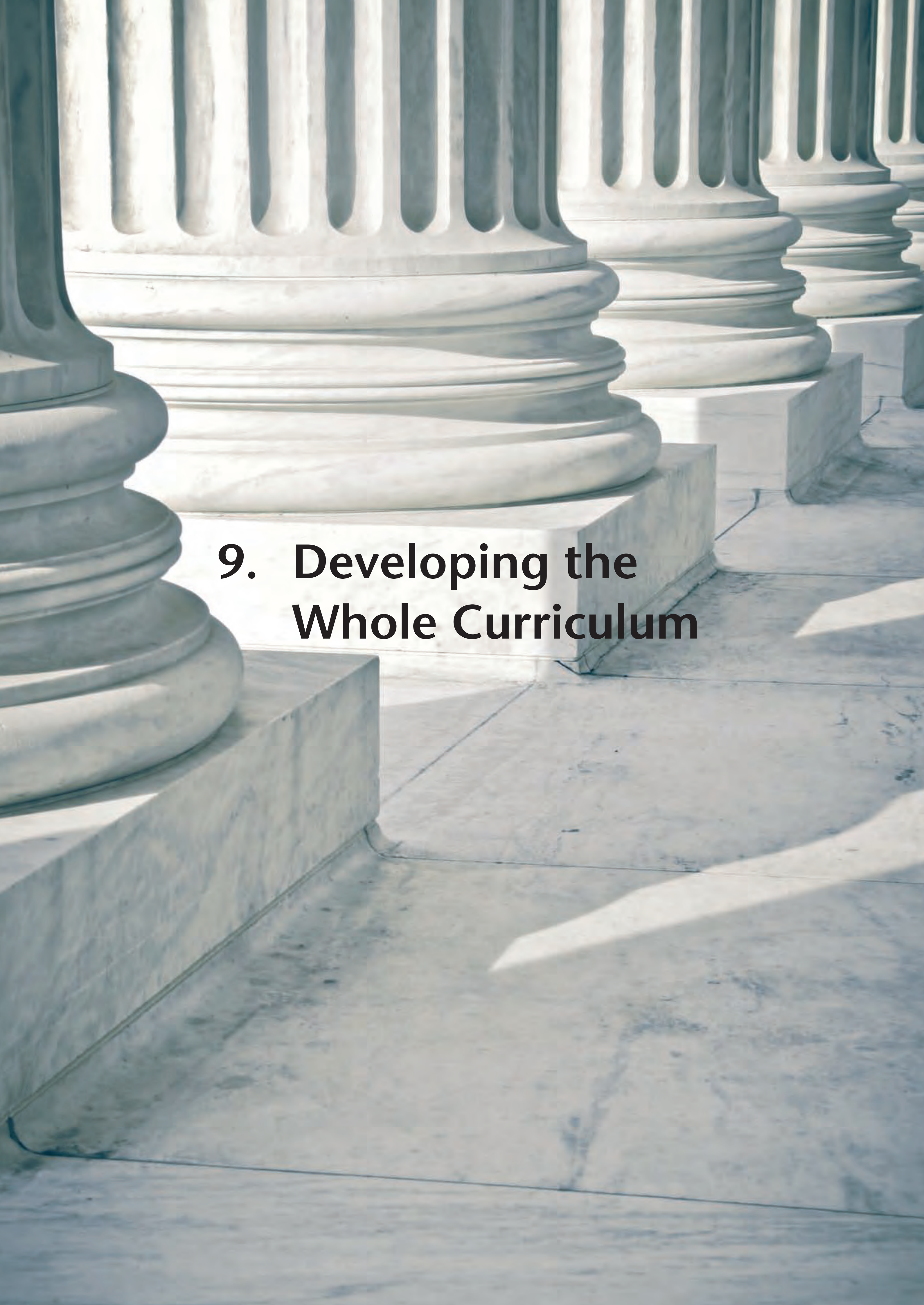
8.9 A Perspective for the Future

There is now more than 20 years experience in project-based learning and computer-assisted learning, but there has been little progress made in properly integrating these two strategies. The individual autonomy of staff, for their particular course, has acted against a planned integrated approach. Academic leaders have also failed to initiate the changes which are available to enhance the student's educational experience while producing engineers with the capabilities that are required for practice in the 21st Century.

Nor has there been much progress in successfully pooling our resources and expertise so that our teaching is more efficient. Cooperation between Universities to share experience and development costs is a sensible strategy that can be initiated with considerable benefits and without detriment to either party. But it doesn't extend beyond high level aspirations and strategic lobbying.

University classes look little different from how they looked 20 years ago, apart from students downloading our PowerPoint slides, which academics all insist upon writing for themselves, believing that they are effectively discharging their educational responsibilities. The pressures to do more with less are increasing. If we are to work smarter, we need to pool our resources. Meaningful cooperation can be mutually beneficial by improving the effectiveness of engineering education, attracting more students, improving the pass-rates and enhancing the efficiency of the process.

It's time that engineering academics developed a coherent approach to project-based learning supported by computer-assisted learning and assessment, so that students are enabled to learn the basic skills at a time convenient to themselves, and academics can spend their time working with students *beyond the basics* in professionally relevant project work to develop real engineering expertise.



9. Developing the Whole Curriculum

9.1 Overview

Developing a whole curriculum is a major challenge. It is rarely done in isolation as it is usually developed in an engineering school from existing components. Consequently, there is a desire to minimise the number of new subjects created. However, this cannot be permitted to over-constrain the design of a transformed program. Even where engineering is a new discipline within a university, it often needs to fit with existing programs in science and mathematics. Again, these programs may provide constraints that make it difficult to start with a clean design.

Nevertheless, the previous chapter shows one way of simplifying the process by having largely common first and second years, where students engage broadly in the fundamental principles that underpin engineering work. They do this through a project-based curriculum supported by online learning modules. This provides individual students with a series of pathways to achieve their development of the specified graduate attributes.

If we think about curriculum as a building with multiple floors, then it provides a visual metaphor. In the building, each floor has a series of rooms in which specialised subjects or topics are examined and learning modules accessed. The building has central spaces, such as a reception, that provide an introduction to each floor. There is also a central column that carries lifts and services, which gives the building structural stability and it allows users to move up and down between floors.

This visual metaphor is very helpful to understand and to design a curriculum, which similarly should have a central spine to provide the connections and stability between the years and semesters and also special-purpose rooms for individual subjects. Students will progress through the building from bottom to top, acquiring expertise and experience along the way.

Several universities have adopted this kind of curriculum architecture: 25-50% of each semester is devoted to project work, which is responsible for the development of the whole professional. The remaining 50-75% represents the technical modules that support the projects. The next section provides some detail of some of these programs as exemplars for new programs.

Before a new curriculum is developed it is essential to establish understanding and agreement on the education principles to be followed. The issues include:

- Project based learning in teams,
- Student-centred learning,
- Availability of a suitably equipped home room for students,
- Importance of student motivation,
- Opportunities for practical realisation of project outcomes,
- Acceptance of student differences,
- Information technology facilities for information dissemination, access, reference, sharing, interaction, submissions, evaluation, feedback and e-portfolios,
- Provision of international perspectives,
- Realisation of Washington Accord graduate attributes,
- Formative assessment in addition to summative assessment,
- Staff training and support,
- Provision of learning facilitators/facilitation,
- Involvement of the profession and employers,
- Program Advisory Committee,
- Practical component: laboratories, e-lab, projects, work experience,
- Program effectiveness evaluation,
- Quality assurance.

9.2 A Project Centred Curriculum Structure

Typical PBL curricula rely on a spine of project-based subjects through the entire curriculum. This is usually either 50% of the curriculum (e.g. at Aalborg University in Denmark [120], Central Queensland University [121]) or 25% of the curriculum (e.g. Chemical Engineering at the University of Queensland, Australia, [122]). This means that in each semester, students will do one project based subject plus 2 or 3 subjects developing their knowledge, understanding and capability. This allows the project subjects to deliver the whole-of-engineer education (the full set of requirements of the accreditation system) while technical subjects can concentrate on developing fundamentals such as mechanics, fluids, thermodynamics, etc.

These technical subjects should use best practice student-centred learning and they may also include small projects to help students to make the connection between theory and practice. However, it does mean that the technical subjects can deliberately focus on the technical outcomes rather than trying to place them in a broad context. This can be quite helpful for both students and staff. For students, they can concentrate their minds on different aspects on different days of the week. For staff, they may wish to concentrate on the technical domain of their research.

The University of Queensland curriculum in Chemical Engineering is shown schematically in Figure 1. The spine of project courses is shown on the left, aided by a sequence of subjects that provide the technical and mathematical skills for the projects. The sequence on the right represents electives and specialisations.

The first two years can be made common and general-purpose, as described above. They have an important role in developing the foundation of the key attributes and capabilities of engineers. Years three and four are then designed to achieve the development of understanding of the engineering technology in the area of major focus of the degree and its responsible professional application. This would comprise a sequence of major projects supported by technical modules.

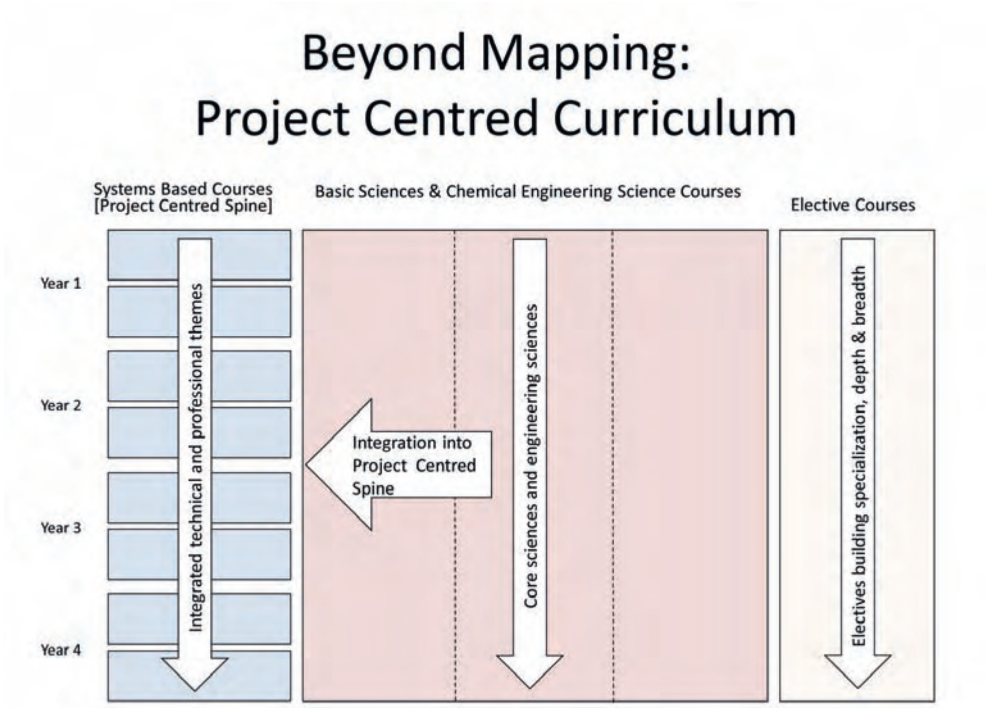


Figure 1: Structure of a Project-Based Curriculum [122].

9.3 Curriculum Mapping Approaches

Obtaining clarity of what needs to be in the curriculum, can be usefully achieved through a curriculum mapping process. Anna Carew and others at University of Tasmania used conversational auditing of the Engineers Australia Stage 1 Competency Standards [123]. The Washington Accord outcomes, or other national accreditation requirements, could be utilised similarly. Working through each of the intended outcomes, involve academics in answering these three questions:

1. Do students develop this attribute in each subject? (Score: 0 = no; 1 = they practise this attribute; 2 = they practise it and it is assessed; 3 = it is taught, they practise it and it is assessed.)

2. If the score is 1, 2 or 3, what activities are used to learn and assess the attribute? Provide documents, or links to documents, as evidence.

3. If 2 or 3, what % of the final assessment mark does this represent?

This process provides a first pass at what should be, or is actually, happening in individual subjects. The proportion devoted to each outcome can be calculated and assessed. Does it fall within the guidelines established by the accreditation body and/or the university?

Doug Auld and Tim Lever (USyd) have developed a rubric that defines five levels of attainment for each of the graduate outcomes [124]. This is similar to the work done at the University of Wollongong, where three levels were defined for each outcome. Such rubrics map out more clearly what the intended outcomes are across all the capabilities.

With these levels of outcome defined, it is then possible to map a curriculum to show how each outcome is achieved in total and across each year of the program. An example is CCmap (Oliver et al [125]) and CCmapper from Geoffrey Roy and Jocelyn Armarego [126]. An example output from the latter is shown below (Figure 2). This analysis is based on a linguistic analysis of the Engineers Australia Stage 1 Competency Standards (provided in section 3.3.2) against the outcomes from the CDIO Syllabus, which uses five levels of attainment [127]:

1. To have experienced or been exposed to,

2. To be able to participate in and contribute to,

3. To be able to understand and explain,

4. To be skilled in the practice or implementation of,

5. To be able to lead or innovate in.

The figure shows that only one of the Competency Standards reaches level 5, "lead or innovate in", namely element 2.2, which is "fluent application of engineering techniques, tools and resources". This is not a surprising outcome.

Some elements reach level 4, "skilled in the practice of", all of them in the technical domain:

1.1. Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

2.1. Application of established engineering methods to complex engineering problem solving.

2.2. Fluent application of engineering techniques, tools and resources.

2.3. Application of systematic engineering synthesis and design processes.

2.4. Application of systematic approaches to the conduct and management of engineering projects.

Most of the others reach level 3, "understand and explain". A similar analysis could be conducted for any existing engineering program using the data collected earlier. This would give a powerful visual summary of the educational outcomes for any engineering program.

All of these mapping tools provide useful ways of finding out what is being achieved by the current curriculum. They facilitate decisions about what should remain in the curriculum and what should be changed. They also provide a useful tool to assist in establishing the intent of a transformed curriculum/program design, and then if applied regularly can provide a useful tool for quality assurance and regular enhancement of the curriculum/program.

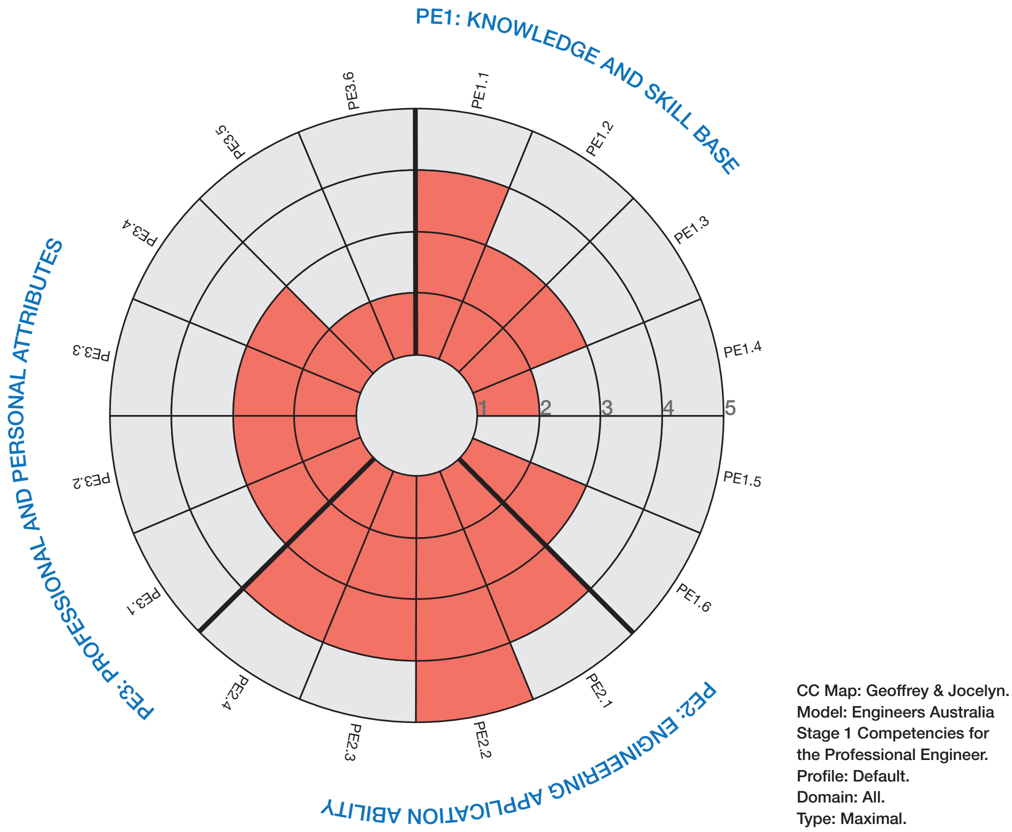


Figure 2: Radar plot of Competency Standards versus CDIO levels of attainment.

9.4 Conceiving a New Curriculum

Developing a new curriculum is quite a challenge, but it provides the opportunity to aim at a best-practice solution. The recommended strategy is a project-based curriculum that is general purpose in years one and two and which provides the opportunity for students to become more specialised in subsequent years. It is suggested that the basic building block of the design or project studio be a half of one semester's work. This provides scope for time consuming, team-based project work and it provides time for skill development based on online learning resources or other means. Some examples of such projects have been provided in the previous chapter for civil engineering. This chapter uses mechanical engineering as an example for consideration.

Mechanical engineering is concerned with machines and fluid systems. These are made up of solid and fluid materials and are governed by energy principles. Systems engineering principles are clearly at the heart of designing mechanical engineering systems.

On a bigger scale, engineering serves society's needs for food and water, shelter and security, transport and communication, health, and so on. Thinking about the engineering challenges of the future, the fundamental concerns are for sustainable and responsible use of our water, energy and material resources as system solutions are designed and implemented. Such thinking could be used to design an engineering education program using four guiding themes: sustainable systems; materials; energy; and water, in each year of the program (Table 1).

A set of studios has been proposed, although others could be chosen. The concept is to use general-purpose studios in years one and two, to develop broad engineering fundamentals and capabilities, which are followed by more advanced and specialised studios in years three and four. The example presented has studios outlined in the first four semesters that could be undertaken by students studying any engineering specialisation. The range of studios available for the later semesters would reflect the engineering school's capacity and mission.

Studios should be reasonably self-contained so that students could choose them in various sequences and from various disciplines, including non-engineering disciplines. For example, "desalination plant design" could have chemical, mechanical, electrical, civil and environmental engineering students all involved as well as environmental scientists and business students. Students would access online learning materials as required and would be mentored by experienced academics and engineers. One of the difficulties of current engineering curricula is that they are so inflexible that it becomes impossible for students from other disciplines, particularly non-engineering disciplines to participate in engineering project work with the possible exception of projects between structural engineers and architects. Studios provide these sorts of cross-disciplinary learning opportunities if the student goals and assessment are established consistent with the student's background and learning objectives.

Table 1: A studio-based Mechanical Engineering Program.

Semester	Theme	Year 1	Year 2	Year 3	Year 4
1	Sustainable systems	Challenge (the role of engineering in society plus developing an engineering career)	Planning health care centres in the Solomon Islands (Management of engineering work)	Develop a new product/business (Entrepreneurship)	Disaster relief planning and design
	Materials	Robotics (Statics, Dynamics, Mathematics, Signals, Programming)	Building/vehicle structure design (Solid Mechanics, Materials, Mathematics)	Vehicle crash testing (Finite Element Method, safety, human mechanics)	Design of Unmanned Aerial Vehicle
2	Energy	Electrical Power Generation (Circuits, AC/DC, Networks, Frequency/Time)	Renewable energy design (Thermo-Fluids, Electrical power, Mathematics)	Design of Manufacturing Systems (Mechatronics)	SAE Formula racing team
	Water	Water Use and Treatment (Fluids, Hydrology, Epidemiology)	Solid waste treatment and recycling	Desalination plant design (Processes, fluids, structures, public health)	Waste water treatment in Cambodia

Table 2: Typical Mechanical Engineering Program [128].

Semester	Year 1	Year 2	Year 3	Year 4
1	Engineering, Society and Sustainability	Renewable Energy Systems	Management of Design	Professional Project Part 1
	Engineering Design 1	Mechatronics Principles	Solid Mechanics 3	Technical elective 1
	Engineering Mathematics 1	Solid Mechanics and Materials 2	Dynamics and Control	Technical elective 2
	Engineering Mechanics	Mechanics of Machines 1	Thermo-Fluid Mechanics 3	General elective 2
2	Manufacturing Systems	Mechanical Design 1	Mechanical Design 2	Professional Project Part 2
	Engineering Mathematics 2	Mathematics and Statistics	Mechanics of Machines 2	Technical elective 3
	Solid Mechanics and Materials 1	Thermo-Fluid Mechanics 2	Introduction to Computational Engineering (FEM)	Technical elective 4
	Thermo-Fluid Mechanics	General Elective 1	Engineering and Enterprise	General elective 3

9.5 Transforming an Existing Curriculum

Starting with a clean slate is useful to reset our thinking about curricula. However, what happens when we already have a well-established program? How can we move to a studio-based model from a content-based model?

Consider the mechanical engineering program (Table 2) [128]. It is a collection of content focussed topics, organised to fit the semester schedule. How could this program be transformed according to the principles described above?

The basic principle is to balance theory and practice by including a coherent project and design sequence with at least one subject per semester. The first two years should include a strong foundation of engineering fundamentals. Can we make the structure of the program clearer for the students?

In the proposed new program (Table 3), most subjects have been combined to make larger, double-sized modules, each worth half a semester's work. These subjects are combined design and analysis subjects, including both project work and skill building, as explained above. Each subject gives students a clear view of an engineering application in the life of a mechanical engineer.

There have been minimal rearrangements of the sequence of material. Mechatronics has moved from second year to first year to combine with Manufacturing Systems. Thermo-Fluid Mechanics 1 has moved from first year to second year to combine with Renewable Energy Systems. Management of Design was merged with Engineering and Enterprise in third year. Introduction to Computational Engineering (the Finite Element Method) has been combined with Solid Mechanics 3, also in third year.

The Engineering Mathematics has been combined with engineering subjects to provide context to the mathematics. However, it might

Table 3: Revised Mechanical Engineering Program: version 1.

Semester	Year 1	Year 2	Year 3	Year 4
1	Engineering, Society and Sustainability and Self: introducing an Engineering Career through Design	Renewable Energy Systems: introducing Thermo-Fluids	Management of the Engineering Enterprise	Professional Project Part 1 and Technical elective 1
	Engineering Mechanics with Engineering Mathematics 1	Solid Mechanics and Materials 2 with Mathematics and Statistics	Dynamics, Control and Mechanics of Machines 2	Technical elective 2
				General elective 2
2	Manufacturing Systems: introducing Mechatronics	Mechanical Design 1 with Mechanics of Machines 1	Mechanical Design 2 with Thermo-Fluids 3	Professional Project Part 2 and Technical elective 3
	Solid Mechanics and Materials 1 with Engineering Mathematics 2	Thermo-Fluids 2	Finite Element Method and Solid Mechanics 3	Technical elective 4
		General Elective 1		General elective 3

Table 4: Revised Mechanical Engineering Program: version 2.

Semester	Theme	Year 1	Year 2	Year 3	Year 4
1	Professional practice	Engineering, Society, Sustainability and Self (introducing an Engineering Career)	Management of the Engineering Enterprise	Engineering Entrepreneurship	Professional Project Part 1 and Technical elective 2
	Structures	Design of Structures 1 (introducing Engineering Mechanics and Mathematics 1)	Design of Structures 2 (Solid Mechanics and Materials 1 and Mathematics 2)	Design of Structures 3 (Solid Mechanics 2 and Mathematics and Statistics)	Cross-disciplinary design studio 1
2	Machines	Design of Machines 1 (introducing Mechanics of Machines 1)	Design of Machines 2 (Dynamics, Control and Mechanics of Machines 2)	Design of Manufacturing Systems (introducing Mechatronics)	Professional Project Part 2 and Technical elective 4
	Fluids	Design of Fluid Systems (introducing Thermo-Fluids 1)	Design of Renewable Energy Systems (including Thermo-Fluids 2)	Computational Solid and Fluid Mechanics (introducing the Finite Element Method)	Cross-disciplinary design studio 2

be more useful to disaggregate the mathematics further into smaller modules that are spread more uniformly across the program. The modules which are available from Loughborough University, as discussed in Section 6.3, provide one way of developing the mathematical knowledge on an as-needed basis.

So far, this is a soft combination of subjects to better link design and theory in project subjects with skill development. Can we do better to produce a program that is more coherent with clear sequences of capability development?

Version 2 is shown in Table 4. This example demonstrates that it is possible, without a great deal of reorganisation or loss of content, to move a traditional program along the path towards a studio-based curriculum. There is still work to do on specifying the projects for each subject, but this should not be too difficult a task. No doubt further reorganisation can deliver additional improvements. The objective is to break out of the content model into a learning activity model of curriculum.

In Table 4 subjects have been grouped into horizontal streams, which run through years one to three: Professional practice, Materials, Energy, and Fluids. Year 4 provides the capstone Professional Project plus technical and general electives. Note that most subjects are now based around design: design of structures, machines and thermo-fluid systems. Supporting skills are professional practice and advanced computational skills. Students use electives to deepen their knowledge in specific areas: technical, professional or generic.

This version is coherent and straightforward. It focuses on the key outcomes for a mechanical engineer: machines, structures and thermo-fluid systems as well as professional skills. It does this by developing each theme in each year – four themes in each year, supported by online learning and assessment. Students would have an overview of mechanical engineering practice by the end of first year. Each subsequent year, they would deepen their understanding and ability to practise engineering.

The technical and general electives have been combined into cross-disciplinary studios such as Business Development or Design for Human Factors. Engineering Entrepreneurship has already been used to replace one combination of technical elective plus general elective.

9.6 Summary

Current engineering programs tend to be a collection of useful modules rather than a coherent action plan to develop the young engineer. Students are often forced to figure out the connections as they are confronted with questions such as: Why are we learning this subject? How does it relate to my future career?

This chapter has provided one example of a studio-based engineering program based on mechanical engineering. It has also demonstrated how to take a typical mechanical engineering program and group the subjects into larger modules. With some slight rearrangement, a coherent program emerged which focuses each year on the development of the graduate engineer using a series of project and design studios. Each semester has only two subjects (modules) each of which is a combination of design project and technical capability development. Students will be able to easily follow the sequence of themed subjects (four themes per year) and to see the increase in capability development from one year to the next. In the final year, students have space to deepen their capabilities in particular areas as they plan their transition into the workplace.

Of course, much remains to be done to implement such a program. Apart from the documentation required to define the program and its new subjects, there would be much work to do to convince academic colleagues to try an arrangement of this form. Fortunately, the new program can use much of the content of the previous program as the basic building blocks for the new project-centred curriculum. Changes of mindset by academic staff will be the hardest obstacle to overcome as the change to personalised student-centred learning is the critical component of realising the benefits of a rearranged curriculum.

10. Achieving Transformation

10.1 The Dilemma Facing Engineering Education

The question that is unresolved is: How are the changes that have been identified as both essential and desirable going to be realised? There has been extensive documentation in the literature of engineering education that a transformation of engineering education is essential. There is also widespread agreement in the literature about the methods and approaches that can be introduced to achieve the necessary transformation. Both the need for, and the elements of, this necessary transformation have been confirmed by numerous investigations and reports. The principles of necessary transformation outlined in this report are consistent with these published analyses. Transformation is about major changes: Making minor changes is not the pathway to transformation.

However, there is an almost total lack of action by universities to realise the essential transformation. It is a difficult system problem. It is a problem that must be addressed by all institutions, all organisations, all units within those organisations, and all people that are part of the system of engineering education. Contributed Panel No. 15 authored by Professor Anette Kolmos neatly summarises the problem by stating that **each** of the following elements must be present within an organisation to achieve transformation:

- Vision
- Consensus
- Skills
- Incentives
- Resources
- Action Plan

She highlights the fact that the absence of any one of these is likely to result in failure. Achieving all of these elements within a university should be considered highly difficult, as they are change resistant organisations, but it must not be considered impossible. Universities have the responsibility for engineering education and consequently they must accept the responsibility for the implementation of the transformation that has been clearly identified as essential. While there are some aspects of change occurring in some universities, they are not progressing on the scale, or with the speed, that even closely approaches what is necessary. The changes required by universities in relation to engineering education, must be considered to be of major proportions; they will not occur without commitment and interventionist strategies. The first step is the acceptance of the need to implement this transformation as a matter of urgency.

Past experience indicates that change within a university is unlikely to succeed unless there is a strong influence for change produced by sources outside the universities. Elements for change ***must*** originate from stakeholders external to the universities. These should include:

- Major Engineering Employers,
- Professional Engineering Organisations, and
- Governments.

Which group is responsible to trigger the process that can commence transformation? As suppliers, it is unlikely to be the universities, even though there are progressive elements within them. The employers are the consumers and should be leaders in the presentation of the case for transformation, but they often have only indirect relations with universities. The Professional Engineering Organisations, as accrediting authorities and representatives of the engineering profession have an obligation to seriously address this issue. Most have conducted reviews and prepared reports that indicate the need for the transformation of engineering education, but have trusted that the reports would lead to action by others. As representatives of the members of the profession and as the responsible accreditation authorities, they should be supporting the need for transformation to government, universities and employers on behalf of the communities that they serve. It is time for them to be part of the solution instead part of the problem. The future of the profession is in their hands.

The establishment of national "Councils for Change" that co-ordinate these three groups and can ensure the accountability of the universities may be a useful strategy. Together they can drive, and insist upon, the required transformation if they employ “carrot and stick” strategies to ensure that the implementation by the universities is appropriate.

Employers have an interest in the availability of an adequate numbers of graduates who have the graduate attributes and skills essential for the future of their organisations, the capability for continuing development and a commitment to the profession of engineering. They should be prepared to provide financial support for universities that commit to transformation. However, collectively they do not have a strong record of relating to and influencing universities. It is clear that they could benefit from closer relations with universities, but they are usually prepared to remain at arm’s length in their relationships with them. They occasionally establish joint research and development programs, but there is potential for increased mutual benefits if they accepted a willingness to establish strong ongoing relationships. They could benefit from activities such as: staff interactions, mutual projects, staff exchanges, student internships, student project challenges. The need for transformation provides an opportunity for employers to benefit from effective partnerships with universities, as they are also major beneficiaries of an enhanced supply of appropriately educated engineering graduates.

Government has a similar interest in universities contributing the necessary skills, with an appropriate gender and social mix, for the innovation and entrepreneurship essential to achieve sustainable national development. Much of their expenditure is related to projects that are complex and dependent upon technology for their realisation. However the shortage of engineering project skill has handicapped governments. Environmentally sustainable stable economic growth is the primary objective for governments and engineers are critical to project design and implementation. Governments can be major beneficiaries from a transformation of engineering education that delivers more and more effective engineers. For the essential transformation of engineering education it will be essential for government to provide an incentive to universities by providing some of the resources necessary for the realisation of this objective, conditional upon their commitment to participate. They could also consider requiring the universities to collaborate in the transformation process to reduce the cost of engineering education programs.

Professional Engineering Organisations that are responsible for the accreditation of engineering graduates, have a major responsibility for, and can perform a key role in, achieving the transformation of engineering education in the interest of the future of the engineering profession. As signatories to the Washington Accord, many have already accepted responsibility to implement rigorous accreditation processes. These accreditation processes should be changed to become based on the demonstrable achievement of ***each*** of the Washington Accord Graduate Attributes, to approved standards specified by each university, by ***each*** graduating engineering student, before they are recognised for entry to the Profession. If this was appropriately implemented the required transformation of engineering education would follow.

Their Assessment Panels should focus on the Assessment Record of ***each*** student’s achievement of the Graduate Attributes. This should be available in the student’s e-portfolio. Panel members could be selected to ensure that the panel has expertise in each of the WA attributes (Section 3.1): technical understanding, technical engineering capabilities, community responsibilities and personal capabilities, while having a minority of university academics. Implementation of this new approach to accreditation would need to follow the implementation of the transformation of engineering education programs at each university. Universities that did not implement transformation of their programs appropriately, within a prescribed period, should lose accreditation of those programs.

It is considered that the recommended co-ordinated action of engineering employers, professional engineering associations and government could provide the necessary incentives for the transformation of engineering education. Creating a sense of urgency in the universities presenting professional engineering programs is a necessary pre-condition for successful transformation, as it can unleash a progressive commitment to change.

Contributed Panel No. 15:

Achieving Curriculum Change in Engineering Education

Professor Anette Kolmos

UNESCO Chair in Problem-Based Learning in Engineering Education, Aalborg University, Denmark

Introduction

Since its establishment in 2007, the UNESCO Chair in Problem Based Learning in Engineering Education (UCPBL) has been involved in faculty development within engineering education. The UNESCO Chair is running three main types of activity: 1) research projects and research training of PhD students 2) Master's programme in Problem Based Learning in Engineering and Science Education for academic staff 3) diverse types of consultancy and capacity-building activity. In 2011 there are ten academic staff members related to the Chair, 15 PhD students, more than 50 academic staff have been enrolled in the Master's education, three international conferences have been held, and more than 35 workshops have been held at host institutions or at universities all over the world.

Within engineering education there is a growing awareness of the need to educate new types of engineers who are able to participate in global, collaborative and sustainable innovation and implementation processes. The need for change is addressed by engineering societies, and conferences and workshops on new ways of teaching and learning. Reviewing the literature, there is an increasing number of places that utilize PBL principles in one way or another. There are many small changes taking place in single courses; however, a more fundamental change in engineering education towards more student-centred learning, complex problem analysis and complex problem solving, interdisciplinary knowledge and competences, and global and intercultural understanding at a curriculum level is progressing very slowly.

From a research point of view, there is plenty of evidence that more active learning methodologies increase students' motivation for learning and increase deep learning. From a theoretical learning perspective, motivation is an important factor in the learning process, and if students are motivated, they learn more (Barneveld and Strobel, 2009; Dochy et al., 2003; Faland and Frenay, 2006; Prince and Felder, 2006; Schmidt and Moust, 2000).

However, educational change is difficult. Kotter (1995) defines sense of urgency as the first stage in an integrated change process, and maybe what academia needs is some kind of emergency driver not only as external requirements from government and accreditation level, but as an internal driver among academics. Change in the approach to learning will only happen if there are both external and internal drivers and if the internal drivers are approached in both a top-down and a bottom-up strategy. Change in engineering education towards more student-centred learning is change of a holistic and organic organization, including all levels of the organization and not least the relation between education and the research activities.

External drivers

Triple helix is a strategy for innovation based on close collaboration among government, businesses and higher education. This approach slowly saturates the development of higher education in general and engineering education in particular. The Europe 2020 strategy including the seven flagships witnesses an overall European strategy for closer collaboration among all of the stakeholders and especially for the development of sustainable innovation (Europe 2020).

The Bologna Process in Europe stresses in particular that the important objective for engineering education is to improve graduates' competences in innovation and entrepreneurship. Furthermore, there is a clear aim for more student-centred learning, and the global trend towards formulating learning outcomes also points in this direction (Leuven Communiqué, 2009; Bologna Process).

In Europe there is also a tendency to change the management systems, moving from elected systems to more appointed systems with dominance of external boards. On one hand, this raises discussion about academic freedom, but on the other hand it fosters closer collaboration between engineering education institutions and companies in both research and education

Vision +	Consensus +	Skills +	Incentives +	Resources +	Action Plan +	= Change
	Consensus +	Skills +	Incentives +	Resources +	Action Plan +	**= Confusion**
Vision +		Skills +	Incentives +	Resources +	Action Plan +	**= Sabotage**
Vision +	Consensus +		Incentives +	Resources +	Action Plan +	**= Anxiety**
Vision +	Consensus +	Skills +		Resources +	Action Plan +	**= Resistance**
Vision +	Consensus +	Skills +	Incentives +		Action Plan +	**= Frustration**
Vision +	Consensus +	Skills +	Incentives +	Resources +		**= Treadmill**

Figure 1: Elements in a successful change process (Thousand and Villa, 1995).

(Kogan, 2000).

Globally there is a visible trend that accreditation and new national assessment systems are being developed and implemented, and more countries are becoming part of the Washington Accord. The development of quality assurance systems also creates new challenges to encompass systems that support student-centred learning and that go beyond accreditation of lists of textbooks to really facilitate learning outcomes.

These external drivers set the scene for change in engineering education, and national governments set the criteria for institutions. As an example, many European countries have set up criteria for institutions to achieve higher completion rates as part of the public funding schemes or give bonuses for higher recruitment into engineering and science.

The external drivers are extremely important for change in engineering education, and if the external drivers do not facilitate a change in direction for more sustainable innovation and entrepreneurship, the institutional motivation will not increase.

Internal institutional drivers

However, the internal institutional drivers are equally important, and at the institutional level there are many levels and actors that need to be taken into account. Curriculum change involves not only the structure of the curriculum, but also all of the actors involved: students, academic staff, managers and administrators. A basic curriculum change towards more student-centred learning and sustainable innovation is about educating new types of engineers. It is not just a change in a single course – it is a change in the curriculum so that there is coherence among the courses and a progression and strategy for the learning of engineering knowledge, skills and competences. Sustainable change will have to be rooted in the course level as well as the system level, and this is a conceptual change in the approach to teaching and learning that involves cultural change.

Moesby (Moesby, 2004; Thousand and Villa, 1995) has defined six internal drivers as premises for successful change at the institutional level: vision, consensus, skills, incentives, resources, and action plan. If all of the areas are addressed in an organization, this might lead to an organizational change; however, if one or two of the elements are lacking, different types of organizational and personal tensions and confusions might be created.

Both Kotter (1995) and Fullan (2001, 2005) mention the importance of visions and the lever of leadership. However, research results show that very often there is a lack of vision in educational change processes (de Graaff and Kolmos, 2007). In particular, visions for the future are some of the key points in an institutional change process, and it is vital to involve academic staff in the formulation of the visions in order to create ownership and motivation. Without ownership of visions, they will not become drivers for change for the management team or for the academic staff who have to carry out the change.

In order to plan a change process encompassing all of the elements, there is a need for both top-down and bottom-up strategies. Researchers point out that all organizational levels have to become involved if the goal is successful change (de Graaff and Kolmos, 2007; Kolmos, 2002; Scott, 2003). Bottom-up strategies are not efficient because staff will leave and then the change will disappear if it is not institutionalized. Top-down strategies are Figure 1: Elements in a successful change process (Thousand and Villa, 1995)

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In order to plan a change process encompassing all of the elements, there is a need for both top-down and bottom-up strategies. Researchers point out that all organizational levels have to become involved if the goal is successful change (de Graaff and Kolmos, 2007; Kolmos, 2002 Scott, 2003). Bottom-up strategies are not efficient because staff will leave and then the not efficient because they create resistance in the system and create a surface organizational change without a cultural change. However, the two strategies supplement each other and make change possible. Therefore, the management level is important, as is the motivation of the academic staff running the courses.

Global community drivers and change agents

Globally the recipe for change is more or less the same: in order to manage institutional change, it is necessary to have top-down and bottom-up processes, visions, realistic plans, qualified staff, etc. One important component is the education of some core change agents – some of the academic staff who can provide inspiration, and who possess knowledge of alternative practices and ideas about how to utilize these ideas in their own institutional culture. These change agents have to be educated, and they can get a great deal of inspiration in global or regional communities with the exchange of international experiences. These networks cross institutional and national borders, give the possibility of reflection on own practices, and get inspiration for further development.

There are no guarantees for successful change to PBL. Each change process is unique, and the cultural and contextual issues in particular will play an important role. There are many "pockets" of advanced practice that can foster inspiration across cultural and national borders despite the expected cultural boundaries. There are many constraints in achieving a successful change process, but the strategy to avoid obstacles is to focus on possibilities.

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10.2 Achieving Change Within the University

Most universities are unfamiliar with major transformational change. This is a challenging process at any time and in this particular case it is difficult because of the scale and complexity of the objective. The starting point is the consideration of the six elements noted by Kolmos and listed in Section 9.1.

- **Vision.** Experience indicates that successful vision must be created and shared by staff members at different levels in the organisation. It is quite unlikely to be successful if driven from the senior levels of the organisation without a shared vision being developed throughout the various sections of the organisation that are to be involved. The goals of the project should be transparent. It is important for them to be communicated widely so that the commitment is clear, but also that the what, why, when and how have also been considered and will be available to facilitate the transformation process.

It should be noted that the change to a learning-centred education with more extensive use of ICT and student-learning spaces is an issue that has significant implications for all the university. Universities will be confronted by the need to change educational methods and practices in their other disciplines too. They have been strongly criticised [85] for being slow to change their methodologies in the face of the Information Technology Revolution and the possibilities which it provides to enhance learning effectiveness. This provides the university with the possibility of considering the transformation of engineering education as a trial for progressive changes in other disciplines, welcoming observers from them, and reporting widely both the progress of the project and its impact on student development, achievement and satisfaction.

- **Consensus.** The transformation project can only proceed when an adequate consensus has been reached, at the different levels in the organisation and with the various groups that will be affected by the changes. It may be necessary to limit the scope of the initial project to sections which can demonstrate consensus.

Consensus is only likely to be created when all the major impacts have been identified and the necessary changes in policy and procedure agreed to in principle. These will include changes in course structure and the assessment of graduate attributes. The key issue is likely to be the major change in the role and manner of presentation of academic staff and their relation to students. This will need to be addressed and, preferably, the opportunity provided to observe project-based learning and student-centred learning models that inform about the nature and direction of transformation. Are engineering academics prepared to explore these alternatives in an open and constructive manner?

- **Skills.** The next issue is the provision of development opportunities for staff to enable them to explore the educational principles, under the guidance of staff with experience as engineering educators, to become familiar with the objectives that are to be realised and the practical details of the methods that are to be utilised [102]. Opportunities to participate in realistic situations, both as observers and as practitioners under guidance, are particularly valuable in establishing familiarity and confidence. All aspects of the program should be covered: graduate attributes, PBL, project ideas, learning experiences, teamwork, facilitation of student-centred learning, project realisation, laboratory experiences, student e-profiles, assessment of the graduate attributes, ITC skills and resources, e-learning resources, etc.

- **Incentives.** This could be the critical issue. Many universities operate with research as the primary activity for staff as it brings status and funding to the department and university. Education, which is the primary objective from the community's perspective, often slips to a poor second. Research is commonly the major factor in promotion and consequently becomes the primary focus for staff, with "the teaching" component of their activities being "a necessary distraction" from the "important" work of research and publication. Some universities will need to enhance the priority given to the education of undergraduate students who are the fundamental reason for their existence and usually the source of their base funding. It may be a difficult policy shift to bring these two important roles of the university back into a balance of esteem. Also the objective is not to promote teaching as an activity, but to achieve the desired outcome which is education using the more effective method of student learning.

  Additionally the transformed program requires sufficient staff to have had broad experience as engineers and this may require the recruitment of new engineering-experienced employees. It can also be achieved by the provision of opportunities for existing teaching or research oriented staff to enhance their professional engineering experience.

  It is critically important that all staff engaged in this complex transformation process know that their commitment to participate will be appreciated and rewarded in recognition for promotion and appointment to leadership (including professorial) positions. The University's commitment to such a major change cannot be transient or superficial. It must permeate all relevant parts of the university as a key priority in which it is not just necessary, but essential, to do things differently from how it had been done previously.

- **Resources.** Appropriate resources are necessary to introduce a transformation of engineering education. As the majority of universities have resource constraints, the financial support of government and industry in providing assistance, on the condition that universities commit to transformation, is considered essential. The largest expense will be the capital expense associated with progressively reconfiguring the students learning spaces. However, there are also additional capital costs associated with updating laboratories, providing project implementation spaces and equipment, provision of software packages for design, simulation and modelling and computer systems to support the new learning paradigm. Additionally there is a capital cost with developing and implementing the new curriculum, identifying the most suitable web-based materials to support student learning and providing training and support for academic staff in the introductory phase of the program. Capital (and recurrent) costs can be minimised if a common curriculum is utilised for the first two years of the program across all engineering disciplines, and also if there is collaboration between universities in program implementation. When operational, the recurrent cost of the transformed program can be expected to be significantly reduced from that of existing programs. A financial plan must be developed to provide the certainty needed for program implementation.

- **Action Plan.** Planning of every aspect of the program's implementation is of paramount importance. In addition to the skill development, the provision of staff incentives and the resource allocation, it is necessary to plan all the other numerous actions and teamwork necessary to introduce a new program with a new ethos. The list of required actions is very long. Many items have been mentioned in previous sections however it is worthwhile to note some of them again. In principle the program should be student-learning centred from recruitment to graduation. Adoption of this major philosophical change by all staff will not be easily achieved, but is highly important for the success of the transformation process. Policies on program structure, assessment of graduate attributes, result recording, work experience, facilitators, student e-portfolios, program evaluation and ITC facilities may need to be changed and this will impact on the administrative sections of the university. The plan should include employer participation, identification of facilitators and their employment conditions, identification of projects, facilities for project realisation, home-room establishment, hardware and software of the IT resources, etc.

The transformation of engineering education requires participation and support from academic staff in other departments or sections of the university. They will need to understand that their cooperation in supporting the engineering program is essential and that they will be required to participate in experiential learning activities as required by the engineering school and not to continue the delivery of the programs normally provided by their service department.

Relations with employers need to be strong to ensure the effectiveness of the program. This may have implications in relation to projects, facilitators, work experience, employment opportunities, membership of Advisory Boards, project evaluation, experimental facilities, learning resource assistance, etc. Engineering enterprises need to be very supportive of the universities in the difficult change period, but it is a time to build relationships of the type that can benefit both parties into the future.

10.3 Taking Steps to Achieve Transformation

The transformation of engineering education is a very necessary objective for the benefit of our societies as they are critically dependent upon engineers to design and implement technological solutions that are sustainable and socially responsible. Without this transformation there will be insufficient, and inadequately educated, engineers seriously constraining the operation and development of our various societies. Transformation of engineering must become a high priority project in our various countries. It is an achievable objective, even though it is a very ambitious project affecting the majority of universities in the world.

Transformation should commence with some trial and demonstration projects that prepare the way for widespread collaborative extension. Which Universities are prepared to accept the challenge and lead the way? The principles to be followed have been developed in earlier sections and summarised in Section 5.1. The Washington Accord graduate attributes must be achieved by all graduating students. A new curriculum is required, developed around Project Based Learning. A student-centred approach to learning using e resources is essential. The program must be cost-effective. The program for the first two years could emphasise a broad approach to engineering which reflects the multi-disciplinary nature of most engineering projects and be a common foundation program for all the engineering disciplines (and even all universities with the choice of projects providing an individual identity for each university). The identification of the most suitable e-learning materials (in each major language) is a task that could be readily shared between students and staff of all universities without the collaboration limiting the autonomy of any university. There could also be a continuing sharing of staff experience, advice and ideas on a collaborative staff website. Cooperation and interaction can only benefit all engineering schools and their students. International Clearinghouses for student and staff resources, and to facilitate collaboration, could be very useful.

The programs in the final two years are likely to emphasise a particular engineering discipline, reflecting the focus, strengths and size of each university and the needs of employers, but a collaborative approach of universities could still be of benefit and enable the efficient identification of useful and effective e-resources and project ideas for both students and staff. It is suggested that some national trials, using a collaborative approach, subjected to rigorous evaluation and which share outcomes in a compatible format, would be very beneficial to all engineering education universities. Trials and experimentation should precede widespread implementation.

For the number of students (both male and female) that are attracted to the engineering profession to be significantly increased, the professional engineering organisations must devote considerable effort to the development of the community's understanding of the role of professional engineers and the importance of their activities to the functioning of society. It is not unreasonable to expect major engineering companies to also assist in this process. The goal should be to attain an understanding of the social responsibility of the engineering profession that is comparable with that of the major professions competing for students: law and medicine.

Student numbers entering engineering programs would also be increased if the secondary school students were able to develop the student's interest in the technologies. Some schools use design, build and construct projects to successfully motivate students, but the major difficulty is the limited number of teachers with an appropriate understanding of technology. Additionally many schools have a major problem attracting sufficient teachers with strong understanding of the mathematics and science which are fundamental tools of technology. It would be very beneficial if some secondary school teachers, during their training program, undertook the two engineering foundation years, as part of their preparation. It would equip them well to broaden the student's knowledge of mathematics, science and technology and to better advise students about technology and engineering careers.

10.4 The Transformation Challenge for Universities

The Franklin D Olin Engineering College (Section 4.6.3), is the shining example of what engineering education could be, when the need for transformation is accepted. While it is a special case, having commenced, well resourced, without a pre-history, it should inspire all universities that the goal of transformed engineering education programs is realisable. The need for universities to respond is real. To achieve this objective they need the support of professional engineering organisations, engineering employers and governments.

> **The challenge:** *"to aim for the transformation of engineering education, for the benefit of all societies",* **is extended to all engineering departments in all universities.**

Transformation of engineering education is required at a time when the traditional university model is under increasing pressure from many different directions. These pressures include:

- Cost pressures because the traditional teaching model is expensive in staff costs.
- Governments are not committed to maintain their level of funding to public universities.
- Cost pressures for students make it essential for many students to work while studying to enable them to pay the university fees and to meet the living costs. (Over 80% of university students in United Kingdom are working while studying.)
- The number choosing distance education (open learning) programs is increasing quite rapidly. (1 in 10 in UK).
- Students are under time pressure and they welcome the opportunity to access "teaching" material via the web and to use social networks to discuss it with their peers.
- Students have moved to new technologies quicker than the staff of the universities. They are familiar with the technologies, have used them in their previous education experiences and they utilise them extensively for social networking.
- Many universities have become financially dependent upon the income generated by international students. These enrolments could be placed at risk by open learning institutions using information technology if student-learning focussed universities are not available.

The message that universities must undergo major change is not a new message, but it is rapidly becoming increasingly urgent. Their educational role must be reconfigured in the information age to be more effective and less expensive. This publication addresses one of the university's most important professional education fields and describes the fundamental changes which are essential in engineering education. We are confident that the suggested changes are achievable and consistent with the nature of changes that universities must implement as they face a challenging future. It requires the commitment and vision of their leaders and their staff to follow the journey associated with this transformation of engineering education while they have the opportunity to do so. We trust that it will receive their endorsement as an essential component of their future strategic plans. The appropriate and effective application of technology, in the interest of our various communities, is dependent upon the implementation of this essential transformation of engineering education in our universities.

It requires universities to raise the priority of their education responsibilities to being no less than their commitment to research responsibilities. If a university is not prepared to do this, it cannot transform engineering education. However engineering research is also essential for the progress of our societies. It should involve the creation of innovative solutions to the some of the many issues of importance to our communities, and that will have significant economic and human benefit. For many universities the profile of their engineering research is toward the fundamental end of the research spectrum. An applied research focus, associated with realising innovative breakthroughs and achieving effective solutions to actual problems, is also required and should be the objective for the engineering units of our universities. Research of this nature has an excellent fit with the project based learning strategy essential for the transformation of engineering education. It would create and strengthen the linkage of the engineering schools to engineering companies, industry groups and government departments, with associated benefits for staff and students. The graduating students should have been confronted, during their programs, with challenges that introduce them to the thrill of achieving an effective innovation during their formative years, and enable them to succeed in their career as professional engineers.

11. Conclusions

There is a critical need for a transformation of engineering education. The key elements relating to the achievement of this essential transformation of engineering education within universities are:

1. The present short-comings in engineering education are readily identified as they have a major impact upon our communities as a consequence of an insufficient number of engineers being educated, and their skill-set being inadequate for their roles.

2. Engineering education must be exciting, relevant and seen as socially responsible, to attract and retain students.

3. There is an extensive literature developed by organisations, individuals and groups of academics that have been analysing, considering, devising and evaluating potential approaches to achieve the transformation of the engineering education system.

4. Investigations, considerations, and reports provide support for the changes in engineering education that have been highlighted in this publication. These include changes in curriculum, pedagogy, objectives and implementation using project based and student-centred learning. Their effective use can also improve the completion rate of students.

5. The appropriate approach to achieving a transformed engineering education experience has been outlined and it presents exciting opportunities for the students while providing significant benefits for employers, societies and governments.

6. In the community's interest, and as a matter of urgency, the engineering employers, governments, accrediting authorities and professional engineering associations, must support the universities to achieve the implementation of the essential transformation in engineering education and consider how they will each participate to facilitate its realisation.

7. The curriculum should be focussed on providing personal learning experiences which develop the students as engineers instead of focussing on the presentation of technical content.

8. The changes required are of major proportions. Implementing such changes must be the responsibility of the universities and their staff. The program structure and content, mode of delivery, objectives, student experiences, staff responsibilities and roles, student assessment, the use of information technology, are all likely to require major change.

9. Engineering science has become the focus of the majority of existing engineering education programs. It is essential that the engineering profession is entered via education programs that develop in their graduates the attributes of creative and informed, capability and responsibility, which are essential for the practice of engineering.

10. The delivery of the required transformed engineering education system will necessitate major changes in how universities operate and the role of their staff. Its implementation will be difficult and those responsible will require support as they address each of the identified issues.

11. Achieving the essential change within the universities is the most difficult stage in the process of transforming engineering education. Developing the understanding, within academic managers and their staff, of the new educational paradigm that is required and expected, and then supporting them in its delivery, is of vital importance.

12. Universities must be prepared to change their policies, practices and facilities to enable the delivery of the transformed engineering programs.

13. The academic staff responsible for the delivery of engineering courses should

be encouraged and assisted to facilitate personalised student learning by utilising student-centred learning methods to replace their current staff-centred lecturing and teaching.

14. Governing bodies of universities with engineering programs should consider placing the transformation of engineering education, with specific measureable targets, in their strategic plans.

15. The universities should be encouraged to collaborate in the exploration, planning and implementation of the transformation of engineering education programs, by sharing experience and expertise relating to curriculum resources and projects, to maximise effectiveness while minimising operational costs.

16. The collaboration of universities on student projects, student competitions, student exchange, industry interaction, computational software, e-books, accreditation and staff training, can all be beneficial.

17. The universities will need to modify their physical facilities to implement and support the required student-centred learning focus and the program core of project-based learning.

18. Governments and employers should consider the provision of financial assistance to universities for the capital costs associated with the implementation phase of the transformation process.

19. The professional engineering associations, who have the responsibility for accreditation, must change their requirements for the accreditation of graduates of university engineering degree programs by verifying that each graduate possesses each of the Washington Accord graduate attributes, or their national equivalent.

20. The professional engineering associations and the universities should also inform the public and potential students of what is to happen, why and when.

21. The professional engineering organisations must assist the development of an enhanced understanding in the community of the engineering profession and the roles performed by engineers, and promote engineering as an exciting, important and rewarding career to girls and boys in secondary schools.

22. Secondary school teachers require an understanding of the role of engineers, technologists and scientists in society to enable a broader range of students to be motivated and prepared to enter these professions.

23. Engineering employers and the engineering departments in universities should be encouraged to build more effective partnerships as an essential part of the implementation of the transformation of engineering education.

24. A review of the implementation of the transformation of each engineering education program should be conducted, by the appropriate organisation in each country, to hold the universities accountable for its successful implementation within the specified time frame.

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There is a critical need for a transformation of engineering education:

- Engineering education must be exciting, relevant and socially responsible, to attract and retain students, particularly women.
- Personal learning experiences are required using project-based and student-centred learning.
- Transforming engineering education will necessitate major changes in how universities operate and the roles of their staff. This is the most difficult part. It will require changes to university policies, practices and facilities.
- Universities must collaborate in the exploration, planning and implementation of these new programs.
- In the community's interest, the engineering employers, governments, accrediting authorities and professional engineering associations, must support the universities to achieve the transformation in engineering education.

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